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PREPARATION OF THIS DOCUMENT

This publication contains papers presented at the Second FAO Expert Consultation on Interactions of Pacific Tuna Fisheries. The Consultation was hosted by the National Research Institute of Far Seas Fisheries in Shimizu, Japan from 23 to 31 January 1995. It was organized by the FAO Trust Fund Project "Cooperative Research on Interactions of Pacific Tuna Fisheries", in close collaboration with regional and national institutions involved in tuna fisheries research in the Pacific (see the Acknowledgements).

The papers in this publication were prepared by members of TUNET, a network of ten working groups organized by the FAO Project. These working groups are composed of scientists of regional and national institutions studying tuna stocks and fisheries, mainly in the Pacific, but also in other oceans.

Distribution:

FAO Fisheries Department
FAO Regional Fisheries Officers
FAO Fisheries Projects and Programmes
International Fisheries Organizations
National Fisheries Research Laboratories
Members of TUNET (FAO's network of working groups studying tuna fisheries interactions in the Pacific)

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ABSTRACT

This publication includes forty papers and two abstracts of papers presented at the Second FAO Expert Consultation on Pacific Tuna Fisheries held in Shimizu, Japan, from 23 to 31 January 1995. The topics of the papers include:

- reviews of tuna fisheries interactions and their research including methods for their study,
- new methods for studying tuna fisheries interactions and examination of their applicability,
- case studies on tuna fisheries interactions,
- analyses of tuna fisheries involved in interactions and their management, and
- an overview of FAO's project that co-organized and co-sponsored the Consultation.

A supplement of an indexed bibliography of papers on tuna and billfish tagging, which was printed separately, is also included.

The objectives of the Consultation were to:

- review and integrate the outcome of the studies on tuna fisheries interactions,
- summarize the extent of tuna fisheries interactions and unresolved research problems, and
- formulate guidelines for research on tuna fisheries interactions.

The understanding of tuna fisheries interactions was enhanced significantly by recent studies. However, the Consultation noted that the number of quantified interactions is still small due primarily to difficulties associated with evaluating such interactions. The papers providing supporting information for the conclusions of the Consultation are presented in this publication. Interactions were found to vary in significance depending on the biological characteristics of the species involved, the sizes of fish caught, the local and stock-wide rates of exploitation, and the distance among fisheries. In many of the studies presented, the inadequacy of fisheries data was stressed. In addition, the lack of understanding of movements of the fish being studied was noted in several papers. General qualitative guidelines presented in several discussion papers stressed that specifically-designed studies be undertaken to adequately quantify interactions. Well-designed tagging experiments were thought to provide the most reliable information about interactions. Guidelines for the collection of data, biological and ecosystem research, modelling, and alternative methodologies for studying tuna fisheries interactions are also included.

ACKNOWLEDGEMENTS

The editors of this publication thank the authors of the papers presented at the Second FAO Expert Consultation on Interactions of Pacific Tuna Fisheries. The authors are to be commended for bearing with the editors' stream of requests for clarification and changes. The editors are especially grateful to the scientists who took time to carefully referee the papers presented at the Consultation. Evidence of this contribution is reflected in the extensive revision of the papers originally presented at the Consultation.

The Consultation was made possible through the close cooperation of tuna fisheries researchers not only in the Pacific region, but also in the Atlantic and Indian Ocean regions. Funds for the organization of the Consultation were provided by the Government of Japan. The National Research Institute of Far Seas Fisheries hosted the Consultation in Shimizu, Japan. Technical expertise, data, computer facilities, and funds for preparatory work, and for the Consultation itself, were contributed by many institutions, especially:

- Commonwealth Scientific and Industrial Research Organization (Hobart, Australia)
- FAO/UNDP Indo-Pacific Tuna Programme (Colombo, Sri Lanka)
- Inter-American Tropical Tuna Commission (La Jolla, California, USA)
- International Commission for the Conservation of Atlantic Tunas (Madrid, Spain)
- Institut français de recherche scientifique pour le développement en coopération (Noumea, New Caledonia)
- National Marine Fisheries Service (La Jolla, California and Honolulu, Hawaii, USA)
- National Research Institute of Far Seas Fisheries (Shimizu, Japan)
- Southeast Asian Fishery Development Center (Kuala Terengganu, Malaysia)
- South Pacific Commission (Noumea, New Caledonia)
- South Pacific Forum Fisheries Agency (Honiara, Solomon Islands).

The national research laboratories in many countries in Latin America, Southeast Asia, and the South Pacific also contributed significantly to the work before and during the Consultation.

The Food and Agriculture Organization and the editors are grateful for the fruitful collaboration resulting in this publication. Special thanks are extended to the host of the Consultation, the National Research Institute of Far Seas Fisheries, and to the local organizers, Drs Ziro Suzuki, Sachiko Tsuji and Tsutomu Nishida of the Institute.

The editors acknowledge the assistance and encouragement of the staff of FAO's Fishery Resources Division, Fisheries Operations Service and the FAO/UNDP Indo-Pacific Tuna Programme in Colombo, Sri Lanka, and particularly of Dr Alejandro Anganuzzi, Mr David Ardill, Dr John Caddy, Mr Mike Doeff, Ms Joan Harris, Mr Andhi Isarankura, Dr Yasuhisa Kato, Ms Christiane Lagrange-Hall, Mr Mike Mann, and Ms Giulia Sciarappa-Demuro. Also, we would like to thank Ms Françoise Schatto-Terribile of FAO Fishery Information, Data and Statistics Unit for her editorial and logistic help in bringing this document to the publication stage. Mr Manlio Cappucci (The Looking Glass Factory) designed the cover of the publication, for which we are thankful.

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The editors of this publication would like to express their appreciation to all those who participated in the Second FAO Expert Consultation on Inland Fisheries of the Pacific Islands. The authors are to be commended for their cooperation with the editors' requests for clarification and changes. The editors are especially grateful to the contributors who took time to carefully review the papers presented at the Consultation. Their comments and contributions are reflected in the extensive revision of the papers originally presented for the Consultation.

The Consultation was made possible through the active cooperation of many individuals, not only in the Pacific region, but also in the Atlantic and Indian Ocean regions. Thanks for the organization of the Consultation were provided by the Government of Japan, the Nansei Regional Research Laboratory, and the Japan International Cooperation Agency. Special appreciation is extended to Dr. Yasuo Ishii, Director of the Nansei Regional Research Laboratory, and Dr. Shigeo Yamada, Chief of the Japan International Cooperation Agency Fisheries Group, for their personal support and encouragement throughout the Consultation.

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- Japan International Cooperation Agency (Tokyo, Japan)
- Japan Overseas Fisheries Cooperation Foundation (Tokyo, Japan)
- Nansei Regional Research Laboratory (Yokohama, Japan)
- National Marine Fisheries Service (La Jolla, California and Honolulu, Hawaii, USA)
- New Zealand Development Assistance Agency (Wellington, New Zealand)
- Overseas Development Administration (London, United Kingdom)
- South Pacific Commission (Noumea, New Caledonia)
- South Pacific Forum Fisheries Agency (Honiara, Solomon Islands)

The publication was made possible through the cooperation and assistance of the staff of the South Pacific Commission, the Nansei Regional Research Laboratory, and the Japan International Cooperation Agency Fisheries Group. Special thanks are due to the staff of FAO's Fishery Resources Division, Fisheries Operations Service and the FAO/UNDP Indo-Pacific Fishery Programme in Colombo, Sri Lanka and particularly of Dr Alejandro Argumedo, Mr David Ardill, Dr John Caddy, Mr Mike Dept, Ms Jean Harris, Mr Anthi Karandreas, Dr Yvonne Kesa, Ms Christiane Lagenaye-Hall, Mr Mike Meen, and Ms Giulia Scarpa-Dennis.

Also, we would like to thank Ms Françoise Sedaira-Terrible of FAO Fishery Information, Data and Statistics Unit for her editorial and layout help in bringing this document to the publication stage. Mr Manlio Cappucci (The Looking Glass Factory) designed the cover of the publication, for which we are thankful.

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PREFACE

Tunas and tuna-like species are extremely valuable commercially. This refers especially to principal market tuna species (albacore, bigeye, northern and southern bluefin, skipjack, and yellowfin tuna). These species are highly prized for canning, sashimi (raw fish dishes), and other products. The other tuna and tuna-like species, however, also provide considerable in-country commerce and are important sources of protein in some parts of the world. In recent years, the Pacific has become the dominant ocean for tuna landings (about 65% of world catches). Between 1980 and 1994, the annual catch of tuna and tuna-like species in the Pacific increased by about 70% to reach approximately 3 million metric tons. There is potential for even higher sustainable catches of some species.

The intensification and expansion of existing fisheries and the development of new fisheries have led to overlap of areas of operations of large and small-scale fisheries, as well as to competition for the same tuna resources by large-scale fisheries using different gear. Presently, two or more tuna fisheries may be operating simultaneously on the same stock in overlapping geographical areas, targeting fish of similar sizes. In such a situation, changes in the fishing intensity or pattern of one fishery may affect the catches of the other fisheries. Even fisheries operating in different exclusive economic zones (EEZs) and on the high seas may significantly affect each other. This is because many tuna species can undertake rapid, long distance movements or migrations across or even between oceans.

The knowledge of fisheries interactions is essential for rational management of fisheries. The principal market tuna species and many tuna-like species are recognized by the United Nations Convention for the Law of the Sea (UNCLOS) as highly migratory. Recently, considerable attention has been directed to the need for rational management of fisheries for highly migratory species and stocks that straddle adjacent EEZ. Such management would enhance economic and social benefits to the countries involved in fishing, processing, and trade.

From 6 to 8 May 1992, the International Conference on Responsible Fishing was held in Cancún, Mexico, leading to the Cancún Declaration. From 7 to 15 September 1992, FAO organized the Technical Consultation on High Seas Fishing held in Rome, Italy, to consider technical issues related to such fishing. As a consequence of these meetings, FAO has been involved in addressing the issue of flag of convenience. This issue is of major relevance to tuna fisheries and their management because many tuna vessels use such flags of convenience to avoid restrictive measures imposed by certain countries. Also, FAO has actively participated in the development of a Code of Conduct for Responsible Fisheries, which was adopted in 1995 and will apply to both high seas and economic exclusive zones.

In a broader context, fisheries issues were considered at the United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro, Brazil, from 3 to 14 June 1993. The existing programme of action on environment and development (referred to as Agenda 21 or the Rio Declaration) and the two Conventions on Biodiversity and Climate Change are now open for ratification. These initiatives represent an important commitment at the highest national political level to resolve a wide range of problems associated with rational use of marine resources.

Of particular importance to the rational use of resources of tuna and tuna-like species are:

- 1982 UN Convention on the Law of the Sea (UNCLOS) and
- 1995 UN Agreement for the Implementation of the Provisions of the UN Convention on the Law of the Sea of 10 December 1982 Relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks.

According to UNCLOS, fisheries management should to be based on the best available scientific information. The recent attention directed to fisheries management of highly migratory and high seas resources pointed out the need for scientific information on interactions of fisheries directed at tuna and tuna-like species. Article 5 of the 1995 UN Agreement specifically requires conservation and management measures for straddling stocks and highly migratory species to be compatible throughout their range of distribution. .This necessitates an understanding of fisheries interactions.

In the Pacific, there is an additional urgent need to integrate available information and to coordinate fisheries research. The Pacific is the only ocean where there is neither a single ocean-wide fishery body nor a technical programme for tuna and tuna-like species. Some of the Pacific stocks of tuna and tuna-like species are only partly covered by existing fishery bodies and programmes in terms of their areas of distribution. This situation stimulated FAO to initiate a project: "Cooperative Research on Interactions of Pacific Tuna Fisheries" and to create a network of ten working groups of scientists (TUNET) to provide direction and to facilitate the implementation of the project.

To provide an information base for the execution of the project, FAO organized the First FAO Expert Consultation on Interactions of Pacific Tuna Fisheries hosted in Noumea, New Caledonia, by the South Pacific Commission in collaboration with the Institut français de recherche scientifique pour le développement en coopération (ORSTOM) from 3 to 11 December 1991. The First Expert Consultation concluded that there is a potential for interactions occurring among the fisheries directed at tunas and tuna-like species. Empirical evidence for such interactions, however, was available for only few fisheries, and these interactions were quantified for even fewer fisheries. It was unclear whether

- interactions are insignificant among fisheries directed at tuna and tuna-like species or
- scientists are unable to detect these interactions possibly due to various changes to fisheries and resources,

resulting in a too-variable background which conceals the effects of interactions.

The results of the First Expert Consultation were published in two volumes. Volume 1[1] con-tained the Summary Report of the Consultation and 21 papers including reviews of tuna fisheries interactions, and their research, especially methods for their studying as well as papers on case studies on tuna fisheries interactions. Volume 2[2] included 11 reviews on the

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[1] Shomura, R.S., J. Majkowski and S. Langi (eds). 1994. Interactions of Pacific tuna fisheries. Proceedings of the first FAO Expert Consultation on Interactions of Pacific Tuna Fisheries, 3-11 December 1991, Noumea, New Caledonia. Volume 1: Summary report and papers on interaction. *FAO Fisheries Technical Paper* No. 336 Vol. 1). FAO, Rome. 326p.

[2] Shomura, R.S., J. Majkowski and S. Langi (eds). 1994. Interactions of Pacific tuna fisheries. Proceedings of the first FAO Expert Consultation on Interactions of Pacific Tuna Fisheries, 3-11 December 1991, Noumea, New Caledonia. Volume 2: Papers on Biology and Fisheries. *FAO Fisheries Technical Paper* No. 336 Vol. 2). FAO, Rome. 439p.

biology and dynamics of major tuna stocks in the Pacific and their fisheries. An additional four papers of Volume 2 provided background information on some specific tuna fisheries.

Subsequent to the First Consultation, the FAO project encouraged and facilitated cooperative research to address technical problems of tuna fisheries interactions. To assess and evaluate progress in this research, the Second FAO Expert Consultation on Interactions of Pacific Tuna Fisheries was organized in Shimizu, Japan (23 to 31 January 1995) at the invitation of the Government of Japan and in particular of the National Research Institute of Far Seas Fisheries. The specific objectives of the Consultation were:

- review and integrate the outcome of the studies on tuna fisheries interactions,
- summarize the extent of tuna fisheries interactions and unsolved research problems, and
- formulate guidelines for research on tuna fisheries interactions.

Sixty-one scientists attended the Second Consultation. Prior to the Consultation, it was noted that tuna fisheries interactions occur in other oceans and scientists were beginning to address these problems. As they are similar in all oceans, several papers on tuna fisheries interactions in the Atlantic and Indian Oceans were also presented at the Second Consultations and they are included in this publication.

The documentation of the Second FAO Expert Consultation on Interactions of Pacific Tuna Fisheries is given in two publications. The reference to the Summary Report of the Consultation is:

- Shomura, R.S., J. Majkowski and R.F. Harman (eds). 1995. Summary Report of the Second FAO Expert Consultation on Interactions of Pacific Tuna Fisheries. Shimizu, Japan, 23-31 January 1995. *FAO Fisheries Technical Paper.* No. 520. FAO, Rome. 58p.

This publication contains forty papers and two abstracts of papers. The full texts of the latter two papers are printed somewhere else. The topic of the papers include:

- reviews of tuna fisheries interactions and their research, particularly methods for their study,
- new methods for studying tuna fisheries interactions and examinations of their applicability,
- case of studies on tuna fisheries interactions, and
- analyses of tuna fisheries involved in interactions and their management
- an overview of FAO's project that co-organized and co-sponsored the consultation,

A supplement to an indexed bibliography of papers on tuna and billfish tagging, which was printed separately is also included.

The understanding of tuna fisheries interactions was enhanced significantly by recent studies. However, the Consultation noted that the number of quantified interactions is till small due primarily to difficulties associated with evaluating such interactions. The extent of interactions were found to vary in significance depending on the biological characteristics of the species involved. The sizes of fish caught, the local and stock-wide rates of exploitation, and the distance among fisheries. In many of the studies presented, the lack of fisheries data was stressed. In addition, the lack of understanding of movements of the fish being studied was noted in several papers. General qualitative guidelines presented in several discussion papers stressed that specifically-designed studies be undertaken to adequately quantify interactions. Well-designed tagging experiments were thought to provide the most reliable

information about interactions. Guidelines for the collection of data, biological and ecosystem research, modelling and alternative methodologies for studying tuna fisheries interactions are also included.

COOPERATIVE RESEARCH ON INTERACTIONS OF PACIFIC TUNA FISHERIES: FAO'S PROJECT AND THE ASSOCIATED CONSULTATIONS

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ABSTRACT

The objectives of the Second FAO Expert Consultation on Interaction of Pacific Tuna Fisheries held in Shimizu, Japan (23-31 January 1995) are outlined, as are the underlying philosophy and scientific challenges. The rationale for studying interactions among tuna fisheries is detailed, including the recent international developments in fisheries management. The First FAO Expert Consultation on Interaction of Pacific Tuna Fisheries was held in Noumea, New Caledonia (3-11 December 1991) with the support of FAO's Japan-funded project "Cooperative Research on Interactions of Pacific Tuna Fisheries." That project is also described in this paper, including its objectives and the network of working groups (TUNET) that was created for collaborative research. Following the first Consultation, several studies were supported by the project and executed within the framework of the network. The outcome of these and other tuna fisheries interaction studies formed the basis for considerations during the second Consultation. The benefits to, and contributions from, developing and developed countries involved in tuna fishing in the Pacific are acknowledged.

1. INTRODUCTION

The purpose of this paper is to provide background information for the Second FAO Expert Consultation on Interactions of Pacific Tuna Fisheries, so its objectives can be considered and substantiated in a broad context of this information.

The Consultation has been sponsored by FAO's Project entitled "Cooperative Research on Interactions of Pacific Tuna Fisheries" in collaboration with regional and national institutions active in tuna research in the Pacific. The objective of the Project has been to enhance the regional and national capacity, especially of developing countries involved in tuna fishing in the Pacific for addressing scientific problems related to interactions of these fisheries. Underlying the formulation of the Project has been the understanding that research on tuna fisheries interactions should be a long-term activity, of which the Project is an integral part. The ultimate goal has been to optimize benefits from tuna fisheries.

2. SCIENTIFIC AND FISHERIES MANAGEMENT PROBLEMS

2.1 Tuna Fisheries in the Pacific and their Interactions

Tunas and tuna-like species are extremely valuable commercially, especially albacore, bigeye, northern and southern bluefin, skipjack, and yellowfin tuna. Collectively, these species are referred to as principal market tuna species. They are prized for canning, sashimi (raw fish dishes) and other products. The lesser known tuna species, however, should not be discounted because they provide considerable in-country commerce and are important sources of protein in some parts of the world. In recent years, the Pacific Ocean has become the dominant ocean for tuna landings. Between 1980 and 1991, the annual catch of tuna and tuna-like species in the Pacific increased by 68% to about 3 million metric tons (mt). The 1991 Pacific catch represented about 68% of the world's catch of these species. While these very high catches in the Pacific are impressive, some recent studies suggest that there is a potential for still higher sustainable catches of some tuna species.

The increases in the catches of Pacific tunas and tuna-like species have resulted from both intensification and expansion of existing fisheries and the development of new fisheries. These changes have led to an overlap of areas of operations of large and small-scale fisheries, as well as to a competition for the same tuna resources by large-scale fisheries using different gear. Detecting or predicting even this most direct type of interaction, however, is difficult and presents a serious research challenge. Presently, two or more tuna fisheries may be operating simultaneously on the same stock in overlapping geographical areas, targeting fish of similar sizes. In such a situation, changes in the fishing intensity or pattern of one fishery may affect the catches of the other fisheries. A further factor in tuna fisheries interactions is the ability of many tuna species to undertake rapid, long distance movements or migrations across or even between oceans. Under these circumstances, fisheries operating in different exclusive economic zones and on the high seas may significantly affect each other.

A further information on tuna fisheries in the Pacific, a potential for their interactions as well as on the status of the associated tuna stocks can be found in FAO Fisheries Technical Papers 335, 336/1, 336/2 and 337.

2.2 Fisheries Management and Requirements for Scientific Advice

The knowledge of fisheries interactions is essential for rational management of fisheries. The principal market tuna species and many tuna-like species are recognized by the United Nations Convention for the Law of the Sea (UNCLOS) as highly migratory. Recently, considerable attention has been directed to the need for rational management of fisheries for highly migratory species and resources that straddle adjacent exclusive economic zones (EEZs). Such management would enhance economic and social benefits to the countries involved in fishing, processing and trade of these resources. Presently, small-scale tuna fisheries exist in many developing countries in the Pacific, and many of these fisheries operate in the same areas as the large industrial tuna fisheries (purse seine, pole and line and longline).

From 6-8 May 1992, the International Conference on Responsible Fishing was held in Cancun, Mexico, leading to the Cancun Declaration. From 7-15 September 1992, FAO organized the Technical Consultation on High Seas Fishing held in Rome, Italy, to consider technical issues related to such fishing. As a consequence of these meetings, FAO has been involved in addressing the issue of flag of convenience. These discussions have resulted in the establishment of the Agreement to Promote Compliance with International Conservation and Management Measures by Fishing Vessels on the High Seas. The issue of flag of convenience is of major relevance to tuna fisheries and their management because many tuna vessels use such flags of convenience to avoid restrictive measures imposed by certain countries.

In a broader context, fisheries issues were considered at the United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro, Brazil, from 3-14 June 1993. The outcome of this Conference is relevant to fisheries directed at tuna and tuna-like species. The Programme of Action on Environment and Development (referred to as Agenda 21 or the Rio Declaration) and the two Conventions on Biodiversity and Climate Change are now open for ratification. These initiatives represent an important commitment at the highest national political level to resolve a wide range of problems associated with rational use of marine resources.

In response to the pressure to address problems caused by unregulated fishing on high seas, Sessions of the United Nations Conference on Straddling Stocks and Highly Migratory Species were held in New York in July 1993, 14-31 March 1994 and 15-25 August 1994. A Further Session of the Conference to be held next year will determine the final outcome of the Conference. The relevance of the Conference for tuna fisheries management and requirements for research and advice, especially related to problems of tuna fisheries interactions is a subject of separate paper to be presented at the Consultation.

FAO also actively participates in the development of an International Code of Conduct of Responsible Fishing, which will apply to both the high seas and exclusive economic zones. The Code is being formulated on the basis of the 1982 United Nations Convention on the Law of the Sea. It takes into account the 1992 Declaration of Cancun, the Strategy endorsed by the 1984 FAO World Conference on Fisheries Management and Development, the provisions of Agenda 21 of UNCED, the conclusions and recommendations of the 1992 Technical Consultation on High Seas Fishing and the outcome of the UN Conference on Straddling Fish Stocks and Highly Migratory Fish Stocks. The draft Code consists of:

- four introductory articles (Nature and Scope, Objectives, Relationship with Other International Instruments and Implementation, Monitoring and Updating),
- General Principles, and
- six thematic chapters/articles (Fisheries Management, Fishing Operations, Aquaculture Development, Integration of Fisheries into Coastal Area Management, Postharvest Practices and Trade and Fisheries Research).

The Agreement to Promote Compliance with International Conservation and Management Measures by Fishing Vessels on the High Seas is an integral part of the Code.

The Technical Consultation on the Code of Conduct for Responsible Fishing was held in Rome from 26 September to 5 October 1994. On the basis of the material provided by the Technical Consultation, FAO is preparing a revised version of the draft Code, which will be presented to all FAO regional fisheries bodies and the FAO Council. In March 1995, the draft will be submitted to the next Session of FAO's Committee on Fisheries for further technical review and to the FAO Council and Conference in the same year. The draft will be harmonized with the outcome of the UN Conference on Straddling Fish Stocks and Highly Migratory Species. This will be done through a mechanism to be decided by FAO's Committee on Fisheries and FAO's Council. Then, the draft Code will be considered at the 28th Session of the FAO Conference in November 1995.

According to UNCLOS, fisheries management needs to be based on the best available scientific information. The recent attention directed to fisheries management of highly migratory and high seas resources has pointed out the need for scientific information on interactions of fisheries directed at tuna and tuna-like species. This need has also become evident at recent regional and international meetings of fisheries scientists and administrators.

In the Pacific, where most catch of tuna and tuna-like species is taken, there is an additional urgent need to integrate available information and to coordinate fisheries research. The Pacific is the only ocean where there is neither a single fisheries body nor a technical programme directed to tuna and tuna-like species that encompass the entire Ocean. Some of the Pacific stocks of tuna and tuna-like species are only partly covered by existing fisheries bodies and programmes in terms of their areas of distribution. This situation has promoted FAO to initiate a project "Cooperative Research on Interactions of Pacific Tuna Fisheries."

3. OVERVIEW OF THE PROJECT

The execution of the Project has been possible due to a very close collaboration of many countries, their regional and national institutions and their scientists, especially in the Pacific region. Japan has financed the Project under the FAO Trust Fund arrangement. FAO has executed the Project, providing supplementary funds as well as organizational and research support. The collaborating institutions have or had included:

- Commonwealth Scientific and Industrial Research Organization (CSIRO, Australia),
- FAO/UNDP Regional Fisheries Support Programme,
- Fisheries Research Center (New Zealand),
- Inter-American Tropical Tuna Commission (IATTC),
- FAO/UNDP Indo-Pacific Tuna Programme (IPTP),
- National Marine Fisheries Service (USA),
- National Research Institute of Far Seas Fisheries (Japan),
- Office de la Recherche Scientifique et Technique Outre-Mer (ORSTOM), and
- South Pacific Forum Fisheries Agency (FFA).

In addition, national research laboratories of many countries of Latin America, Southeast Asia and the South Pacific have also significantly contributed to the Project.

TUNET, a network of ten Working Groups has been established by FAO to implement the Project. This reflects the need for the involvement of scientists from many countries in addressing scientific problems of tuna fisheries interactions. The topics of the Working Groups have been:

- Methods for Studying Tuna Fisheries Interactions,
- Interactions of Pacific Skipjack Fisheries,
- Interactions of Western Pacific Yellowfin Tuna Fisheries,
- Interactions of Eastern Pacific Yellowfin Tuna Fisheries,
- Interactions of South Pacific Albacore Fisheries,
- Interactions of North Pacific Albacore Fisheries,
- Interactions of Pacific Bigeye Tuna Fisheries,
- Interactions of North Pacific Bluefin Tuna Fisheries,
- Interactions of Southern Bluefin Tuna Fisheries, and
- Interactions of Pacific Small Tuna Fisheries.

The Working Groups include 65 scientists from 20 countries. About 34% of these scientists are from developing countries and international organization working for and/or with developing countries.

Information on the Project's implementation is distributed to through Circular Letters to TUNET Members. The distribution list for these Letters includes 147 fisheries scientists and some administrators from the whole world, 47% of the recipients being from developing countries and international organisations. So far, 23 Circular Letters have been prepared and distributed through air mail and e-mail. The Project has promoted the use of e-mail to distribute information and data and to facilitate the deliberations of the Working Groups. Now, of the all recipients of Circular Letters, 69 have access to e-mail.

In the first year of operation (1991-92), the Project was administered from the FAO/UNDP Regional Fishery Support Programme in Suva, Fiji, but its technical activities were coordinated by the Marine Resources Service of the FAO Fisheries Department. Since the second year of operation, the FAO Headquarters has become the operational base of the Project due to the termination of the FAO/UNDP Regional Support Programme. The Operations Service of FAO Fisheries Department has been responsible for the Project from the logistic and administrative point of view and FAO's Marine Resources Service has continued to coordinate the technical activities of the Project.

4. FIRST FAO EXPERT CONSULTATION

The operation of the Project started from the collation and critical review of information on approaches or methods for studying tuna fisheries interactions and on actual interactions of Pacific tuna fisheries. That review was supplemented by the collation of more general information on tuna stocks in the Pacific and fisheries targeting them. This work as well as the formulation of research and other recommendations were completed at the First FAO Expert Consultation of Interactions of Pacific Tuna Fisheries, which was hosted in Noumea, New Caledonia, by SPC in collaboration with ORSTOM on 3-11 December 1991. The Consultation was attended by 50 scientists from 21 countries. Among them, 27 were from developing countries and international organizations.

The preparatory work to the Consultation was carried out by TUNET's Working Groups. The information assembled before and at the First FAO Consultation was documented in its Proceedings in a form of FAO Fisheries Technical Papers 336/1 and 336/2 (567 pages in total), which contain the Report of the Consultation and 35 papers including comprehensive reviews, methodological and case study papers.

Before the First Consultation, information on tuna resources, fisheries and research in the Pacific was scattered, difficult to access and not integrated. The information presented at the First Consultation demonstrated that there is a potential for interactions occurring between and among the fisheries directed at tunas and tuna-like species. Empirical evidence for such interactions, however, has been available for only few fisheries, and these interactions have been quantified for even fewer fisheries. The resolution of this problem has been a challenge to scientists in general, to the Project in particular and to the related Consultations.

5. STUDIES SPONSORED BY THE PROJECT

Following the recommendations of the First Consultation and subsequent discussions within TUNET's Working Groups, the activities of the Project focused particularly on skipjack and yellowfin tuna. They concentrate on:

- improvement of existing methods and approaches and development of new methods and approaches for studying tuna fisheries interactions, and
- examination, testing and application of methods and approaches for addressing typical tuna fisheries interaction problems occurring in the Pacific.

Such a programme is likely to lead to the greatest benefits to developing countries of the entire Pacific region because:

- very few methods have been developed for scientifically addressing problems of tuna fisheries interactions and their applicability has been mostly unknown, and
- the species selected have been most important to developing countries of the region.

As part of the activities of TUNET's Working Groups, proposals for research on Pacific tuna interactions were formulated and critically referred. The progress in the execution of the proposals supported by the Project was monitored by FAO and TUNET.

Some of the specific studies sponsored by the Project include:

- a modelling of movements of skipjack tuna and resulting interactions of fisheries in the western Pacific,
- a simulation of the dynamics of tuna fleets and fisheries interactions in the eastern Pacific,
- an examination of the status of tuna stocks and interactions of tuna fisheries off the Federated States of Micronesia, off Kiribati, and off Indonesia and the Philippines, and
- a species identification of small juvenile tuna in the catches of Philippines fisheries.

The Project also financed the publication of an indexed bibliography of papers on tagging, which is a major tool for studying tuna fisheries interactions. This bibliography was printed as Special Report No. 8 of the IATTC in 1993. The execution and outcome of the studies will be reported in detail, critically reviewed and integrated at the Second FAO Expert Consultation of Pacific Tuna Fisheries.

6. SECOND FAO EXPERT CONSULTATION

Overview. The Second FAO Consultation on Interactions of Pacific Tuna Fisheries will be hosted in Shimizu, Japan, by the National Research Institute of Far Seas Fisheries on 23-31 January 1995. Its Objectives are to:

1) review and integrate the outcome of ~~the~~ studies on tuna fisheries interactions,
2) summarize the extent of tuna fisheries interactions and unresolved research problems, and
3) formulate guidelines for research on tuna fisheries interactions, concentrating on biological aspects of skipjack and yellowfin tuna in the Pacific.

This information will be documented in the proceedings of the Second Consultation, which will be published as an FAO Fisheries Technical Paper. The Consultation may also make recommendations regarding research on interactions of tuna fisheries in the Pacific and/or other oceans, any follow-up activities and other matters, recognizing that additional funds would be needed to be secured before further substantial research activities can be supported by the Project.

Some 55 papers, including review, methodological and case study papers are expected to be presented and discussed at the Consultation. Objectives 2 and 3 will be achieved by working at the Plenary Session and in small groups. This work will be led by the Moderators appointed well in advance to the Consultation, using materials including the papers to be presented at the Consultation. The preparatory work for the Consultation should assist in achieving its objectives.

Further detailed information on the Consultation can be found in its Programme; an updated version was distributed together with Circular Letter No. 23 to TUNET Members in November 1993. This Programme includes information on the Organizing Committee, objectives, structure, organization, annotated agenda, Chairmen and Moderators of the Consultation as well as the list of papers to be presented. Information on weather conditions, transportation, hotels and excursions in Japan was distributed by the Local Organizers to all recipients of Circular Letters to TUNET Members in October 1994.

Structure and Organization. The following information is provided to Participants to facilitate more efficient and fruitful considerations of the Consultation. To place the objectives of the Consultation in a broader perspective, all facets and types of tuna fisheries interactions will be acknowledged (Agenda Item 4: "Facets and Types of Tuna Fisheries Interactions"), even those not to be considered in detail at the Consultation. Concerns related to interactions will be outlined. General requirements for fisheries management advice and research will be discussed.

As the papers to be presented at the Consultation will be dispatched to potential participants in December 1994, only their aspects of direct relevance to the Objective of the Consultation will be very briefly presented (Agenda Item 5: "Review of Studies on Tuna Fisheries Interactions"). Each presentation will be followed by specific questions, answers and observations (a conference-style session). More general considerations may be flagged during these follow-up discussions, but their full elaboration will be postponed to Agenda Items 6 to 9 ("Extent of Tuna Fisheries Interactions", "Unresolved Research Problems" and "Guidelines for Research", respectively).

Comparisons among the interaction problems, studies, research approaches and methods and other general observations will be made in the context of Agenda Items 6 to 9. These Agenda Items of direct relevance to the Objectives of the Consultation will be advanced by working at the Plenary Session and in small groups (a workshop-style session). This work will be arranged by the Moderators in consultation with the Organizing Committee.

Computer software related to tuna fisheries interactions will be presented in small groups (Agenda Item *: "Demonstration of Computer Software Related to Tuna Fisheries Interactions"). Specific research problems may be discussed also in small groups and reported to the Plenary Session if appropriate (Agenda Item **: "Discussion on Specific Research Problems by Small Groups of Participants, if Required").

The Report of the Consultation is aimed at comprehensively addressing its Objectives rather than at fully or chronologically reflecting all stages of advancing them. The discussions and questions related to individual presentations will be also reflected in the Report.

To facilitate a prompt adoption of Report, Rapporteurs will submit their parts of Report to the secretariat within 24 hours from their completion after consulting their content with the relevant Moderators. Participants will be requested to communicate their suggestions for modifications directly to the Rapporteurs within 24 hours from the distribution of the first draft of Report.

The second draft of Report will be distributed in the morning of 31 January (Tuesday). In the afternoon of that day (Agenda Item 10: "Adoption of Report"), only the issues that could not be resolved directly among individual participants, the Rapporteurs and the Moderators will be allowed to be considered at the Plenary Session.

The Report of the Consultation together with the presented or tabled papers and reports, if appropriate, will be published in the Proceedings of the Consultation in the form of FAO Fisheries Technical Paper (as the Proceedings of the previous Expert Consultation on the same subject).

Challenges. As evident from the large number of papers to be presented at the Second Consultation, there should be now much more information on tuna fisheries interactions and approaches or methods for their studying than when the First Consultation was held. This information will provide substantial input for considerations aiming at achieving Objective 1 of the Second Consultation (see above).

The real challenge for the Second Consultation is to achieve Objectives 2 and 3. This challenge needs to be considered in the light of the outcome of the First Consultation regarding the extent of tuna fisheries interactions (a significant potential for interactions among many tuna fisheries, empirical evidence for few of them and even fewer quantified interactions). At that time, it was unclear whether interactions are insignificant among fisheries directed at tuna and tuna-like species or whether scientists are unable to detect these interactions. This, possibly, might be due to various changes to fisheries and resources, resulting in a too-variable background which conceals the effects of interactions. With the additional information available now and the best expertise expected to be available at the Consultation, Objectives 2 and 3 should hopefully achieved to a very significant extent. This potential outcome is very important for both developing and developed countries to enhance their capacity to scientifically address problems of tuna fisheries interactions, which is the objective of FAO's Project. Therefore, a significant portion of time, effort and resources have been allocated for achieving these objectives.

In the process of fulfilling Objective 2, the extent of suspected interactions, the empirical evidence for them and their scientific quantification will be summarized. It will be discussed whether interactions are a problem now and/or likely to be a problem in the future and if yes, in what circumstances (for what species, fishing intensity and methods, geographical areas, etc.). Types and facets of unresolved research problems critical from the view point of fisheries management will be identified to concentrate further discussions around them.

In the course of achieving Objectives 3, various approaches to studying tuna fisheries interactions will be summarized. Their assumptions and requirements for data, other input information, computational techniques and computer software and hardware will be outlined. The feasibility of their application in various circumstances will be discussed. Conditions under which they may be effective will be identified. Observations will be made on most appropriate ways of formulating and executing research programmes, recognizing the existence of various types and facets of interactions, their uniqueness in many cases and previous experiences with their examination.

In achieving Objectives 2 and 3 of the Consultation, attention will be given to likely future developments in tuna fisheries in the Pacific and their resulting future interactions. These are important considerations because, as mentioned earlier:

- some of the tuna resources in the Pacific are still significantly under-exploited,
- there are anticipated significant future developments in the Pacific fisheries, and
- tuna fisheries interactions are likely to be most pronounced for stocks exploited at nearly optimal or overfished levels.

Implications of discussions and conclusions of the Consultation for the provision of fisheries management advice will be considered in the light of increased interest in management of high seas resources and highly migratory species in particular. If considered appropriate, the Consultation may also make suggestions and/or recommendations regarding the research required to address the most important and urgent problems of tuna fisheries interactions in the Pacific and arrangements for its execution, etc.

7. BENEFITS TO DEVELOPING AND DEVELOPED COUNTRIES

FAO's Project and the associated Consultation should significantly benefit both the developing and developed countries involved in tuna fishing in the Pacific by enhancing their capacity at the regional and national level for addressing scientific problems related to tuna fisheries interactions. The membership of TUNET's Working Groups, incorporates both scientists from both developing and developed countries who study tuna fisheries interactions. Such a composition facilitates the transfer of research methodologies, information and advice from developed to developing countries as well as in the opposite direction, especially regarding the fisheries, data collection and research of the latter countries.

The First FAO Expert Consultation on Interactions of Pacific Tuna Fisheries was well attended by scientists from developing countries and international organizations working for and/or with developing countries (54% of all participants), most of whom were financially sponsored by the Project. The Consultation provided these countries as well as developed countries with comprehensive information on tuna resources and fisheries in the Pacific as well as on their interactions and methods or approaches for studying them. Previously, this information was dispersed and extremely difficult to access.

The studies sponsored by the Project are of direct relevance especially to developing countries. Scientists from these countries have been involved in their formulation and expressions of support for these studies from their governments have been received by FAO.

The Second Expert Consultation on Interactions of Pacific Tuna Fisheries is also expected to be well attended by scientists from developing countries. Most of them will be financially sponsored by the Project. In addition to up-to-date comprehensive information on tuna fisheries interactions, approaches or methods for studying them and improvement to them, the Second FAO Expert Consultation should provide developing and developed countries with guidelines on the applicability and reliability of these approaches or methods, research recommendations and information on the likely extent of tuna fisheries interactions, making generalizations on this extent if possible.

The collaboration of scientists from developed and developing countries should result in an enhanced information on fisheries and the associated data collection and other research, especially on tuna fisheries interactions, which should be now more freely available to all of them. Most newly developed methods or approaches and improvements to the existing methods and approaches to studying tuna fisheries interactions are of particular interest to developed countries. They have a readily available expertise, as well as computer hardware and software to apply these methods or approaches. However, not all of the approaches and methods require the sophisticated expertise and computer hardware and software. The Project should also result in a substantial transfer of expertise from developed to developing countries, increasing their capacity for addressing scientific problems of tuna fisheries interactions.

COMMON THEMES IN THE PROCEEDINGS OF THE FIRST CONSULTATION ON INTERACTIONS OF PACIFIC TUNA FISHERIES

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ABSTRACT

Studies of tuna interaction include examination of fishery statistics, tag-and-recovery data, and the use of models. A review of the proceedings of the First FAO Expert Consultation on Interaction of Pacific Tuna Fisheries noted the difficulty in demonstrating the existence of interaction between and among tuna fisheries. Key factors appear to be the lack of appropriate fishery data, insufficient information on the biology and population dynamics of the species, and a lack of understanding about the influence of the environment on tuna resources.

1. INTRODUCTION

The marked increase in tuna landings in the Pacific during the past decade has raised the issue of interactions between and among fisheries. Pacific island nations have been especially concerned with impacts associated with their domestic fisheries in a context of providing distant water fishing nations access to their Exclusive Economic Zones (EEZ). An international meeting to review tuna interactions in the Pacific was held in Noumea, New Caledonia, from 3-11 December 1991. The meeting reviewed the status of the tuna resources in the Pacific and discussed in detail studies on tuna interaction; the proceedings of this meeting were published in two volumes (Shomura et al., 1994).

The present paper reviews the interaction studies included in the Proceedings of the First FAO Expert Consultation on Interactions of Pacific Tuna Fisheries (Shomura et al. 1994) in order to elicit common themes in methodology applied to interaction studies and to gain some insight on the types of problems involved in tuna interaction.

2. RESULTS

Excluding the species synopses and descriptions of fisheries, there were 20 papers on tuna interaction included in the proceedings. The general breakdown of the 20 papers was one classification of types of interaction, 15 full papers and 4 abstracts[1] on tuna interaction.

Kleiber (1994) noted two types of interactions as (a) indirect competition and (b) direct competition. Indirect competition includes non-harvest competition, e.g., competition in marketing and gear interference; this subject was not part of the consultation. Direct

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[1] Full papers have been published elsewhere.

competition includes "harvesting the same or overlapping resources and secondary effect of one fishery on another's resource". Direct competition was the prime focus of the consultation. The various types of interaction have been described by Anonymous (1988), Kleiber (1994), and Hampton (1994). Hampton (1994) classified interaction into three types:

Type A - Competition for fish at the same stage in their life cycle in the same general area by two or more fisheries,

Type B - The effect of fishing a stock at an early stage in its life cycle upon a fishery that exploits the stock at a later stage, typically with a different gear, and

Type C - The effect of fishing a stock in one area upon a fishery that exploits the stock elsewhere.

There are several ways to classify the methods used to measure interaction; for the present discussion I will basically follow that of Kleiber (1994), who classified the methods as (a) fisheries data and statistics, (b) tagging, and (c) modelling. Table 1 summarizes the interaction papers by methodology and species. Although skipjack dominated the tuna landings in the Pacific (Hampton, 1994), it appears that skipjack was not the focus of much tuna interaction research. The only full paper involving skipjack was Kleiber and Fonteneau (1994), which detailed fishery interactions of skipjack in the eastern Atlantic Ocean. Hampton (1994) in a general review of tuna interactions in the western and central Pacific made reference to several interaction studies on skipjack. Especially noteworthy was the reference to Kleiber et al. (1984) who developed coefficients of interaction based on tagging data.

The most common thread noted throughout the proceedings was the difficulty that researchers encountered in providing proof of interaction. This difficulty was due to inadequate data, insufficient knowledge of the biology and population dynamics of the resource, and the lack of understanding the influence of the environment on tuna resources. Researchers in several studies were able only to allude to the possibility of interaction. Muhlia-Melo (1994) suggested a possible predator-prey interaction between small tunas (*Auxis* spp.) and yellowfin tuna in the eastern Pacific, while Naamin and Bahar (1994) examined catch trends of longline-caught yellowfin in the eastern Indian Ocean and western Pacific, and suggested a possible linkage and interaction of yellowfin between the two areas. No statistical evidence was provided due to the lack of adequate data. In many of the interaction papers, authors pointed to shortcomings in data including the lack of standardized data (Suzuki, 1994), access to data (Hampton, 1994), collection of basic data, e.g., effort statistics (Boggs, 1994), and problems with species identification (Suzuki, 1994; Bayliff, 1994).

The only direct evidence of interaction described in the proceedings resulted from tagging studies. Several authors used results of directed tagging studies to demonstrate interaction. These included skipjack in the Atlantic (Kleiber and Fonteneau, 1994), South Pacific albacore (Murray, 1994), and southern bluefin tuna (Polacheck, 1994). The occurrence of gillnet markings on troll-caught albacore gave direct evidence of interaction

between the troll fishery and the high seas gillnet fishery in the North Pacific (Bartoo et al., 1994) and South Pacific (Murray, 1994).

Table 1. Summary of tuna interaction by methodology and species.

Fisheries Data and Statistics	Tagging	Modelling
Skipjack	**Skipjack** • Kleiber and Fonteneau (Atl.) • Hampton (ref. Kleiber et al., 1984; W. & C. Pac.) • Hampton [ref. projected study in Solomon Islands]	**Skipjack** • Kleiber and Fonteneau (Atl.) • Hampton (ref. Kleiber et al., 1984; W. & C. Pac.) • Hampton (ref. projected study in Solomon Islands)
Yellowfin • Boggs (Hawaii) • Suzuki (W. & C. Pac.) • Medley (W. & C. Pac.)	**Yellowfin** • Naamin and Bahar (Indonesia)	**Yellowfin** • Deriso et al. (E. Pac.)
Bigeye • Miyabe (ocean-wide)	**Bigeye**	**Bigeye**
Albacore • Murray (S. Pac.)	**Albacore** • Bartoo et al. (N. Pac.)	**Albacore** • Kleiber and Baker (N. Pac.)
Northern Bluefin • Bayliff (N. Pac.)	**Northern Bluefin** • Bayliff (N. Pac.)	**Northern Bluefin**
Southern Bluefin • Polacheck (all oceans)	**Southern Bluefin** • Majkowski et al. • Polacheck (all oceans)	**Southern Bluefin**
Small Tunas • Yesaki (Gulf of Thailand) • Muhlia-Melo (Mexico)	**Small Tunas**	**Small Tunas**
Non-species-specific • Kleiber (classification) • Hearn and Mazanov (modelling) • Sibert and Fournier (modelling) • Salvadó (modelling)		

While tagging provided some direct evidence of interaction, several authors noted problems associated with the use of tagging data. These problems included (a) tagging mortality, (b) tag loss, (c) non-reporting of tag recoveries, (d) uneven distribution of tag releases, (e) lack of fishing effort in some areas of species distribution, (f) high cost of tagging experiments, and (g) the generally extended time taken to implement tagging experiments. While some of these factors were accounted for in the studies, the uncertainties of tag-and-recovery data added another dimension to the extensive "background noise" associated with interaction studies. Possibly the most crucial evidence that tagging data should be used with caution was provided by Bayliff (1994). In his

review of interaction with the northern bluefin tuna, Bayliff (1994) noted that northern bluefin tagged over several successive years showed different movement patterns. This variability makes it difficult to draw definitive conclusions or to develop realistic models.

While there is substantial information of the biology of the principal commercial tuna species, several authors noted specific data needs in interaction studies. These included a better understanding of surface and subsurface-caught yellowfin tuna, age and size data for several tuna species, stock structures, and general and specific movement characteristics.

In attempting to interpret fishery data and tag-and-recovery information, researchers noted the lack of understanding of the environment influences tuna resources. Suzuki (1994) suggested that a better understanding of the environment, e.g., the influence of El Niño-Southern Oscillation events, may help to explain changes noted in catch rates. The El Niño is especially important to the tropical tuna species since its influence extends across the ocean basin, changing the thermal structure and circulation pattern. These changes influences the movement of water (Niiler, 1993) and the availability and catchability of tunas. Recently, researchers have directed effort to long-term environmental changes and their influence on fishery resources (Polovina et al., 1994).

Kleiber (1994) noted the problems associated with fishery data and tag-and-recovery information in characterizing interactions of tuna fisheries. Considering the many human and environmental factors involved in tuna fisheries, Kleiber suggests the use of dynamic models to better understand fishery response to changing conditions. He notes that an important feature of modelling is the ability to consider "confounding factors that cannot be controlled in the real world". The use of models to understand interaction is an important iterative process. The model builder initially utilizes available estimates of resource and environmental parameters; subsequently a range of values is used to determine sensitivity of the parameters. These results, thus, provide some guidance to researchers of future information needs. As new data are collected the model is revised and the process repeated.

3. SUMMARY

The proceedings of the First FAO Expert Consultation on Interactions of Pacific Tuna Fisheries highlighted the difficulties in quantifying interactions. While improvements in the collection of fisheries statistics will lead to better assessments of interaction, it appears that development of suitable dynamic models will provide the mechanism to best understand the full process. The models identify critical parameters that need to be further investigated.

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TYPES OF TUNA FISHERIES INTERACTIONS

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ABSTRACT

The principal categories of fisheries interactions are economic competition, stock-mediated interaction, and gear competition. While all three types of interaction may be important, this paper focusses on classifying stock-mediated interactions. Within stock-mediated interactions, there can be direct competition between fisheries, either concurrent or consecutive, and secondary effects on recruitment or trophic relationships. In addition, stock-mediated interactions may depend on movement of the fish. The analysis and assessment of any interaction must take into account the particularities of the situation.

1. TYPES OF INTERACTIONS

As a contribution to the introductory agenda item of this Second FAO Expert Consultation on Interactions of Pacific Tuna Fisheries, I was asked to offer a typology of fishery interaction. This is essentially the same task I had for the first consultation (Kleiber, 1994). Little has changed in the intervening time to suggest a revised typology, but rather than simply copying the text of my previous paper, my plan is to concentrate on a pictorial presentation that was lacking in that paper.

Figure 1 shows a schematic typology of mechanisms by which the activity of one fishery could affect the performance of another fishery. That promulgation of cause and effect from one fishery to another is what we call fishery interaction. The various categories were described at the previous consultation (Kleiber, 1994; Hampton, 1994). Principal categories are: 1) *economic competition*, where the market activity of one fishery affects the market conditions (e.g., price) of another fishery; 2) *stock-mediated* interaction, where one fishery has some effect on the abundance or availability of the target fish population of another fishery; and 3) *gear competition*, where deployment of gear or other operations of one fishery interferes with the operations of another fishery. As before, I have concentrated on stock-mediated interaction. Within that category we have *direct* competition between fisheries aiming to harvest the same individual animals, and we have *secondary* effects in which one fishery impacts the resource of another fishery by some means other than removal of individuals that the other fishery is otherwise destined to catch. Direct competition can either be *concurrent* within the life-cycle of the fish, with fisheries harvesting the same sizes or ages, or it can be *consecutive*, with different fisheries harvesting different sizes, ages, or life stages. A possibly important secondary effect could occur if one fishery depresses the spawning stock which in turn would affect subsequent *recruitment* to another fishery. Other secondary effects could be mediated by *trophic* relationships in which the species harvested by one fishery is either food for, or a predator

of, the resource stock of another fishery. An important cross-categorization within stock-mediated interaction is based on whether competing fisheries are spatially *coincident* or *remote* from each other, that is, whether the interaction effect depends on the movement of fish.

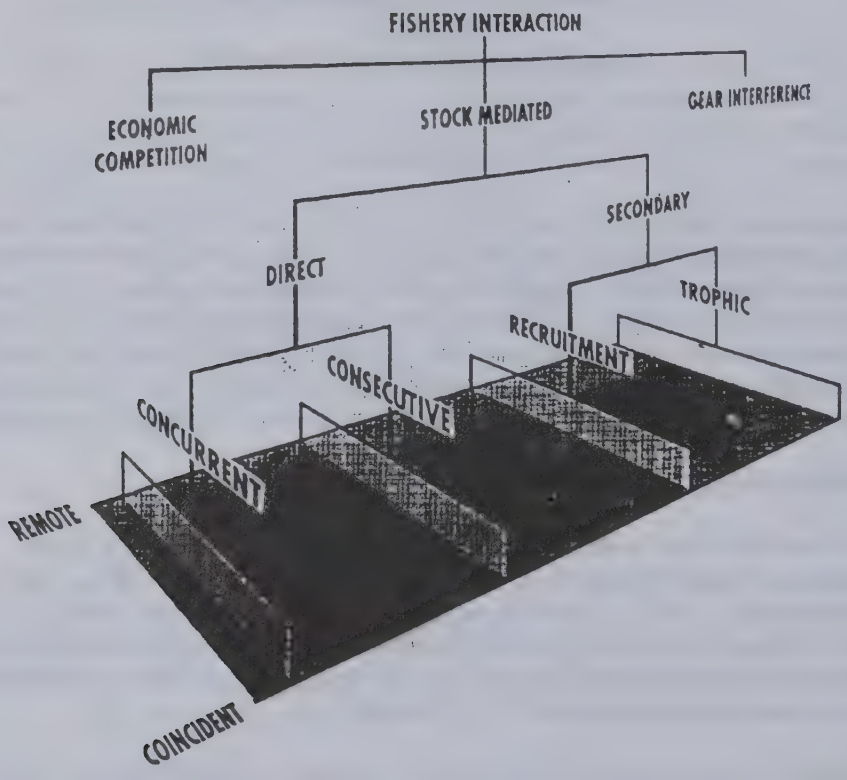

Figure 1. Schematic typology of fishery interaction mechanisms.

Figure 2 represents processes by which various types of stock-mediated interaction can occur by means of a generalized tuna life-cycle with fisheries superimposed on it at various stages. This figure illustrates the fact that binary categories in the typology can be extremes of a continuum. Thus, the distributions of size in the catch of two fisheries can overlap completely, partially, or not at all, and the areas in which fisheries operate can overlap completely or partially, or can be separated by short or long distances.

The schematic structure in Figure 1 relates to strategies for assessing interaction and in particular to the design and complexity of assessment models. With strictly concurrent interaction, knowledge of the exploitation rate in each fishery would be sufficient information for assessments. With consecutive interaction it would be necessary to add size, age, or life stage structure to the model. Recruitment interaction would require a stock-recruitment relationship, and trophic effects would require a multi-species model. Whatever the level of population dynamic complexity, going from strictly coincident

interaction to remote interaction requires the addition of diffusive movement, advective movement or both to the model.

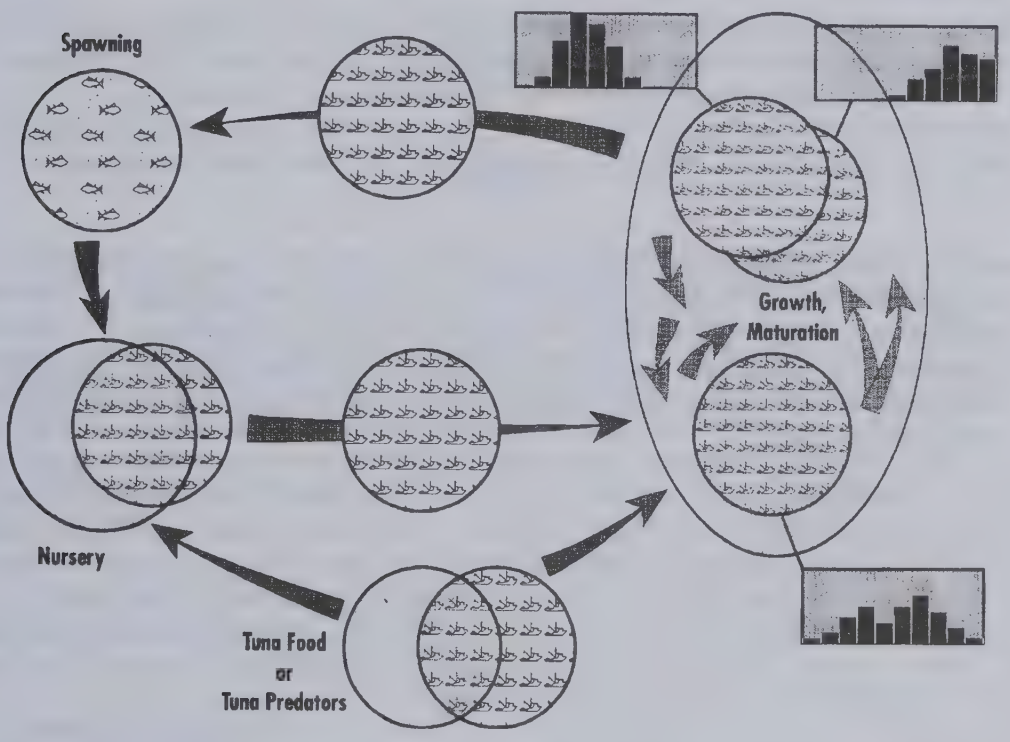

Figure 2. Generalized tuna life-cycle illustrating mechanisms of stock-mediated fishery interaction. The circles shaded with a pattern of boats are fishing fleets impinging on various stages in the tuna life cycle which is represented by circular or oval areas (except for one circle on the bottom which represents tuna prey or tuna predators). The arrows indicate some combination of growth, development, and geographic or trophic movement of fish. The rectangles contain histograms of size or age in the catch.

My emphasis on stock-mediated interaction reflects my inclination and training in population dynamics, but it does not imply that other mechanisms are of lesser importance. Gear interference might be important in some situations, and it is quite possible that economic competition between tuna fisheries is of greater consequence than stock-mediated interaction. For some tuna fisheries it can be said that the market is more of a limiting resource than the productivity of the fish population. A fisheries economist would no doubt be able to subdivide that category in useful ways that would reflect strategies for assessing economic fishery interaction. As with most typologies, there are some things that defy categorization. For example, net marking of escapees from gill nets reduces their marketability when they are later caught by other gear. That interaction could be said to be a hybrid of economic, stock, and gear interaction. The lesson is that analysis and

assessment of interaction in any particular situation must take into account the particularities of that situation, generalized typologies notwithstanding.

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SOME TECHNICAL ISSUES REGARDING THE STUDY OF FISHERIES INTERACTIONS

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ABSTRACT

Technical approaches for studying fishery interactions are discussed. The specific approach in each case depends on the nature of the interaction. Generally, a longer distance (in space or time) between potentially interacting fisheries means a more difficult identification of significant effects. A two-stage strategy is offered as a way of approaching the problem. In the first stage, a conceptual model of how the interaction occurs leads to a refinement of the hypotheses and to the identification of relevant information needed. In the second stage, options for management action need to be formulated according to the immediate objectives. Such objectives might include obtaining better information on the nature of the interaction. Methods for assessing interactions that use data from tagging experiments offer the best chance of providing conclusive evidence of an interaction, as well as quantifying its extent, in a relatively short period of time. Such an experiment can be successful, however, only if there is a reinforcement of the statistical systems in the fisheries involved.

1. INTRODUCTION

Interactions between fisheries exploiting the same resource are a growing problem in fisheries throughout the world. In some regions, resources are being exploited by heterogeneous fleets operating over vast areas, often covering the exclusive economic zones (EEZs) of several nations. Almost inevitably, this will lead to controversies among users of the resources about the extent of the interactions and about the best way to manage the exploitation of the resources.

Our role as scientists is to provide some of the elements that managers will need in order to resolve these potential conflicts. To provide this advice, we rely upon a collection of techniques that can prove valuable to characterise fisheries interactions, provided that we have the data. The objective of this paper is to discuss some of the problems that we will face, together with the technical strategies that we could follow. This review is intended as a starting point for discussion rather than a definitive document, and, in its final version, will incorporate the results of the discussion during the Second FAO Expert Consultation on Interactions of Pacific Tuna Fisheries.

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Before beginning with the review, we need to establish an agreement about how we define and characterise interactions. Therefore, in the next section we will review some of the definitions and classifications of interactions that have been proposed.

As is the case with most management problems related with the exploitation of natural resources, we are faced with a two-stage problem in studying interactions. In the first stage, we need to identify and characterise the problem. That is, we need to formulate a model of how the interaction is operating; and provide values for the parameters that are relevant for the interaction. In a second stage, we must explore alternative management strategies, which means providing managers with a clear view of the trade-offs among the available alternatives; the trade-off is a sensitive matter since different objectives might translate into very different policies being preferred. The second section of this review expands on these themes. The remaining sections discuss the technical approaches that we can apply to the study of interactions, keeping in mind the dual aspect of the problem.

2. THE PROBLEM: WHERE DEFINITIONS ARE REVISITED

As a result of the First Consultation, several definitions of the interaction problems were proposed. The basic concept is that the activities of one (or more) fishery might affect the performance of some other fishery (or fisheries). In order to simplify the examples, I will consider the case of just two fisheries interacting: fisheries A and B. The definition of fishery must be left intentionally vague since, in practice, it will be situation-specific and depend upon the perception of conflicting interests between sectors of the overall fishing fleet. For example, two interacting fisheries could be different gears operating on the same resource or simply two different sectors of the same fishing fleet that differ in where and when they prefer to capture the fish.

Having agreed upon a definition of interaction, we can recognise many different formats and classifications based on the characteristics of the underlying process. Perhaps the first distinction to make is between *resource-mediated* and *direct* interactions (Kleiber, 1994). Resource-mediated interactions occur when two or more fisheries exploit the same resource, whether at the same stage in their life-history or not. We can extend that basic definition to include the case where fishery A exploits a species that provides forage for species B. Resource-mediated interactions will be most difficult to assess, since in many cases, this requires more information about the processes related to the resource (primarily in the dynamics of the population) than is currently available. In a typical scenario, an interaction between two fisheries would be suspected if changes in the performance of one fishery are correlated with the activities of the other fishery. Obviously, it will not suffice simply to say that there is an interaction between those two fisheries. We need to assess the level of the interaction. Furthermore, we would like to know the mechanisms leading to the interaction, since we can postulate alternative hypotheses to explain the trends observed in the data.

The second category involves direct physical interference between gears, a definition that perhaps could be extended to include interference between the fishery and other economic activities, such as industrial or recreational uses of the environment. These are not going to be discussed any further in this review, primarily because direct interactions

do not pose special estimation problems: if two gears interact directly we can almost always set up experiments with the purpose of measuring directly the interaction.

Kleiber(1994) also makes a distinction between *absolute* and *marginal* interactions. Absolute interaction refers to the absolute effect that fishery A has on fishery B, while marginal interaction refers to the effect that a unit increase in the activity of fishery A will have on fishery B. Kleiber(1994) discusses some of the issues that arise when considering these different types of interaction.

In another document, also presented at the First Consultation, Hampton (1994) proposed the following classification of fishery interactions:

- Type A: Competition for fish at the same stage in their life cycle in the same general area by two or more fisheries;

- Type B: The effects of fishing a stock at an early stage in its life cycle upon a fishery that exploits the stock at a later stage, typically with a different gear; and

- Type C: The effect of fishing a stock in one area upon a fishery that exploits the stock elsewhere.

Other distinctions could possibly be based on the symmetry of the interactions. For example, Type A and some Type C interactions can be thought as symmetric, since both fisheries A and B may affect each other's performance. In Type B, usually the early fishery affects the outcome of the fishery exploiting the later life stages (although this depends on the dynamics of recruitment). Considering the symmetry of the interactions leads us to some problems about the stability of both fisheries that are not unlike certain problems in predator-prey systems.

We can exemplify some of the main problems with estimating the level of interactions using the simplified situation where we have two fisheries: A and B, exploiting the same resource. The fish are initially available to fishery A, then the survivors move and become available to fishery B. In that simplified situation, the main number that we are interested in is a conditional probability: the probability that a fish caught by fishery A would have been caught by fishery B. If we denote this probability by $P(C_b)$, we can consider a simple representation of the main processes:

$$P(C_b) = m_{ab}\, e^{-Mt_{ab}} \frac{F_b}{F_b + M_b}\left(1 - e^{-(F_b + M_b)}\right) \qquad (1)$$

This is a product of three components:

1) m_{ab} : The proportion of fish that would have left area A in the direction of area B, except that they were caught in area A,

2) $e^{-Mt_{ab}}$: The fraction surviving the trip from area A to area B (M represents the instantaneous natural mortality and t_{ab} is the transit time between areas A and B; and

3) $\frac{F_b}{F_b + M_b}\left(1 - e^{-(F_b + M_b)}\right)$: The fraction of fish that are caught in area B, where F_b and M_b are the instantaneous fishing and natural mortality rates in area B.

Therefore, we can assess the level of interaction by estimating the number of fish that would have been caught by fishery B (in the absence of fishery A), as

$$N_B^* = N_B + N_A P(C_b) \qquad (2)$$

This simple approximation illustrates some of the main problems that we need to face. First, it is clear from equation 1 that the level of interaction is a function of the exploitation level of fishery B. However, it also depends on the exploitation rate of fishery A (through N_A). Obviously, the migration rate is another critical component; for fishery A, the exploitation rate depends on the residence time, which is a direct function of the migration rates. An interesting feature is that if a population exhibits density-dependent migration rates, the overall level of interaction would be underestimated by a model that assumes density-independent movement (that is, an assumed *per capita* migration rate could actually increase if densities were allowed to increase in area A). The migration rate and the factor representing survival during the transit between areas A and B, also control the degree of coupling between the two fisheries. Assuming density-independent effects (for example, in the natural mortality rate during the passage from fishery A to B) will bias our perception about the effect of fishery A, if natural mortality is actually density-dependent. Knowledge of the variability of this stochastic process is important to assess the strength of the interaction and to interpret possible correlations between the outputs of both fisheries. Note also that the migration rate, in this simplified scenario, is not necessarily a movement of individuals through space; it might be that they simply become less vulnerable to gear A (and more to gear B) as they grow.

This simple example represents a one-way interaction, namely fishery A affecting the outcome of fishery B. In a more common scenario, there will be also a similar set of processes representing the way fishery B affects the output of fishery A. For example, both fisheries might operate at different places of a migratory "circuit" of the population. This leads to the need for consideration of long-term effects of the interaction. If density-dependent effects on population growth are strong, the apparent depressing effect of the catches of fishery A might turn out to increase the long-term average yield of the population (if currently underexploited), although perhaps at the expense of yields obtained by fishery B. Similar situations must be considered from a yield-per-recruit point of view: changing the age-at-entry (by allowing a fishery that targets smaller fish) might increase the overall yield-per-recruit (for both fisheries combined).

All these considerations are compounded by the socio-economic side of the fishery. Size-related differences in price per unit weight and the way the revenues of the fishery are

distributed are important considerations when fisheries of different scale are involved (e.g.: artisanal versus industrial fleets).

The classifications and characteristics of interactions discussed above are all based on interactions of several fisheries based upon a *single* stock. Interactions mediated through trophic relationships (where fishery A exploits the forage base for the target species of fishery B) have not been widely considered, although they have been often discussed in the context of multispecies fisheries and implicitly incorporated in such models. This class of interactions will not be discussed any further in this review: although in principle they might be important. The dynamics of forage species is a problem that adds another layer of complexity, and very few fisheries, have been studied closely enough to correctly specify the underlying processes.

If we consider the classification proposed by Hampton (1994), we notice that the level of interaction is going to be controlled by different sets of variables depending on the type of interaction. In other words, the relevant questions are different in each case. For example, knowledge of the migration rates is not as relevant in the case of a Type A as in Type C interactions. Therefore, knowing the type of interaction allows us to organise our data requirements.

3. A BASIC SET OF STRATEGIES

Suppose that we have been advised of a potential interaction for which we have little prior information. How could we proceed? As suggested in the Introduction, we can identify a two-stage strategy to follow:

1. Set up a conceptual model of the interaction by identifying the interacting components in the fishery and formulate a model of how the interaction is occurring. In some cases, this phase might be the easiest. For example, in a Type A interaction, where the competing fisheries are coincidental in space and time, there will be a much better chance to identify the mechanisms of the interaction than in a Type C interaction.

2. Formulate a management plan that incorporates explicitly the interactions, considering alternative objectives. Here, we should discriminate between allocation problems and management of the overall resource.

The first phase is the one most likely to involve scientists directly, but both stages are obviously related. The identification of an interaction is relevant even if the situation is not such that we can do something about it. Proper management of even a subset of fisheries on a resource requires knowledge about the levels and impacts of all fisheries.

4. STAGE ONE: SETTING A CONCEPTUAL MODEL

4.1 Identifying the Interaction

The natural first step in the analysis of any potential interaction is to construct at least a conceptual model of what mechanisms are behind it. In some instances, this will be a trivial exercise, as would be in the case of two fisheries coinciding in time and space in the

exploitation of a common resource. Other situations, however, will prove to be more complex, with the need for the incorporation of time lags, specific migration timings and routes and even uncertain stock structures. In all cases, the exercise will be valuable from the point of view of forcing us to postulate explicit hypotheses that could explain the data. This is the key element, since in most of those more complex situations we will need to expand our data collection capabilities. Formulating models (at least conceptual models) facilitates the identification of the voids in the available evidence.

If we go back again to our classification of the types of interaction, we see that a Type A interaction poses little problem. That scenario can be well represented by a simple model where the population suffers fishing mortality from two independent sources. In this case, provided that the gear selectivities are similar, we may not even need an age-specific representation. Unfortunately, real life rarely is so simple.

There are several useful ways of analysing catch and effort data to document the existence and level of fisheries interactions. Beginning with the simplest cases, the empirical analysis of series of CPUE data may be useful to some extent (see, for example, Boggs, 1994). We need to emphasise, however, that the analysis of CPUE series has to be done in the spirit of an exploratory analysis and that the prospect of actually quantifying the interaction using just catch and effort data is not good in most cases. The problems with this kind of data for assessing an interaction are multiple. A common first step with CPUE data is to see whether or not CPUE in one area is correlated with CPUE in another area, which could suggest that the same fish are present in both areas. Unfortunately, in many cases, we would be constrained to use short time series with the undesirable consequence of a low statistical power for hypothesis testing, i.e.: it is unlikely that we will be able to detect anything but the strongest interactions. Note also that a correlation measure would not represent a measure of the strength of the interaction, but merely the degree of "commonness" of stocks exploited by the two fisheries. The situation is only aggravated if, prior to the correlation analysis, we have problems in finding the appropriate transformations to improve upon the distributional properties of the CPUE data. Moving to more robust, non-parametric approaches will only make matters worse in terms of the power of the tests. A second problem is that, even if we have tests with adequate power for some data set, the analysis may be affected by confounding factors.

Improvements can be made to simple correlation analyses if we can take some of the confounding factors into account by modeling the CPUE of fishery B as a function of effort in fishery A and a number of other factors that could be related to availability and catchability, e.g., factors affecting fishing power and environmental variables. In other words, we would be standardising the CPUE series in relation to possible exogenous factors. Generalised linear models are a specific technique with flexibility to accommodate different structural assumptions. In such a model, we can include the activity of fishery A (defined as either catch or effort) as an explanatory variable along with other factors that may affect the performance of fishery B, and test the significance of the each factor. Different time lags can also be tested if appropriate. Ideally, we would also want to incorporate the level of exploitation of the resource. It is widely recognised that the level of interaction is dependent on the overall exploitation rate of the population. The rationale is that the competition between different sources of mortality increases as the fishing mortality becomes the most important source of mortality in the population. Assessing the

level of exploitation should therefore be one of the priorities in an initial assessment of an interaction. However, to be able to carry out this analysis, we need a specific set of data that is not always available from the fishery.

We would also want to test for significant statistical interactions in the effect of those factors (i.e., exploitation level and the activity of fishery A). If information is available, we can stratify the data more finely and test for significant statistical interactions in the effects of area-specific levels of activity of fishery A. The disadvantage of this approach is that it is more demanding in terms of data related to the operating characteristics of the fishery and information on the environment at the appropriate time and space scales.

The main problem with any linear modeling approach is that we can never be certain that we have incorporated all the variables that are relevant. Catch, effort and environmental databases with the information and resolution needed are frequently not available. The bottom line is that, unless the data show substantial contrasts in the potential causal factors (i.e., the environment, the activity of fishery A, etc.), we might not be able to discriminate between an environmentally- and fishery-driven trend in fishery B.

The variability of the catch process could be such that it would mask a weak coupling between two fisheries. Therefore, we need to bring in any auxiliary information that could provide information regarding the hypothesised interaction. The latter might come in the form of biological studies about the structure of the stock. Consider the example of two fleets fishing in two discrete time-area strata. The first question that we would like to answer is whether they are actually exploiting the same resource, in the sense that the productivity of the resource in one time-area stratum is linked to the productivity of the resource at the other time-area stratum. The relevant question is: How strong is the coupling between the two areas? That leads us naturally to the question of stock structure, and the techniques currently available to deal with this problem are later discussed.

4.2 Additional Data: Catch-At-Age or Catch-At-Size Information

If catch-at-size or catch-at-age information is available a more realistic analysis of fishery interactions could be achieved. In these circumstances, we can reconstruct the history of the population using a sequential analysis (VPA). If it is possible to reduce the number of parameters, by assuming separability of the fishing mortality or by including indices of abundance for specific groups of ages, we can expand upon the basic VPA and have an analysis with a true error structure. We can even include a specific parameter for interaction and test the significance of the parameter if we can cast the error structure in terms of a likelihood (see, for example, Porch et al., 1994; Punt and Butterworth, 1995). In most cases, however, the parameter estimation will be complicated by the absence of enough contrast in the data or by confounding between factors. For example, natural mortality and movement will be confounded and before we can discriminate between them, we need to incorporate more structural assumptions. This can be done by incorporating a specific assumption about the nature of the interaction and by comparing with a base case where no interactions are assumed. One problem is that, in general, recruitments are not going to be known. In order to be able to better identify the level of interaction, additional information will be needed. This is why, in most cases, tagging data is the best solution for the study of interactions.

4.3 Our Best Chance: Using Tagging Data

A tagging experiment may be a risky enterprise--it is usually expensive, and the possibility that it would not provide enough information to discard some of the hypotheses proposed is high. The design and amount of effort (in terms of number of tagged animals released) will determine the success of the experiment. The analysis of tagging data incorporates some new uncertainties but we can probably tackle most of them. Reporting rates are the most difficult parameter to estimate. Double tagging can be use to estimate tag shedding and, in certain situations, tag seeding can be used to assess reporting rates. Multiple releases in different areas and season can address spatial and temporal variability. Provided that these problems are solved, tagging data can be used as a way to assess exploitation rate, migration rates and potential interactions without having to collect long time-series of fishery data. Therefore, it is not surprising that this has been the preferred area of development of analytical methods. Perhaps the most serious limitation of tagging is that it does not address sources of recruitment and variability of recruitment because we cannot (at least, not yet) tag eggs and larvae.

Several approaches can be found in the recent literature, most of them well represented in the First Consultation. Majkowski et al. (1988) and Hearn and Mazanov (1996) proposed some interesting techniques that do not require a measure of the effort or detailed catch statistics in each fishery and that provide a direct measure of the level of interaction. To some extent, the efficiency of both methods depend on the possibility of re-releasing fish. Unfortunately, the possibility of capturing and re-release tagged fish without seriously affecting their chances of survival is very low, because of the way fish are usually handled during the commercial operations, the primary source of capture.

There is now an extensive literature on analytical tools that can be used to estimate movement rates and residence times from tagging data. Ishii's (1979) work set the basic principles for combining simulation models and tagging data to estimate survival and movement rates. Sibert (1984) presented a two-fishery model that illustrates the basic application for the study of fishery interactions. Hilborn (1990) proposed an estimation procedure in the analysis of tagging data that, being based on maximum likelihood, allows for direct comparisons of nested models. These principles have been expanded in more recent work. Deriso et al. (1991) proposed a model that can provide area-specific estimates of movement rates and residence times. Lebreton et al. (1992) proposed a general approach to model selection and hypotheses testing in models that are not nested based on the Akaike's information criterion. Anganuzzi et al. (1994) illustrated an application of the approach to estimate movement rates and gear selectivity. Some models represent movement as a combination of advective and diffusive processes. Sibert and Fournier's (1994) model represents movement as two-dimensional advection-diffusion processes that are controlled by area- and season-specific parameters. Kleiber and Fonteneau (1994) presented a similar model based on one-dimensional movement. Salvadó (1994) proposed an extension to continuous cases by representing the transition probability densities through Green functions. Mullen (1996) estimated area- and time-specific diffusion rates by comparing consecutive spatial distributions in abundance.

However, in spite of the different philosophies behind each of the methods, the basic problem in the analysis of tagging data remains the same: accounting for the tags that were not recovered.

4.4 Accounting for the Missing Tags

In any analysis of tagging data, we estimate the probability of recovering a tag, as a function of various processes, some of which will be of primary interest to us since they relate directly to the quantification of interactions. In the models, we have several ways of representing the losses of tags. Generally speaking, we can assume that the loss of tags is due to two kinds of processes:

1) Type-I loss: a one-time event, in the sense that we assume that a certain proportion of the tags are lost shortly after being released or after the fish are caught. A number of processes can be postulated that might contribute to this loss. For example, the losses that occur shortly after tagging might be due to shedding of those tags that were not properly attached, or to mortality of the fish due to improper handling. The reasons for tags not recovered after the capture of the fish might be multiple (e.g., tagged fish are not noticed, tags might get lost during handling of the fish, or in the mail), but we pool them all under the category of reporting rate.

2) Type-II loss: a constant rate of attrition of the tags from the population. Tag-shedding might continue throughout the life of the tagged population. But tags also disappear from the population due to natural mortality and emigration (either permanently or temporarily) from the exploitable population (i.e.: they are no longer available to the fishery).

Some of the Type-I losses are amenable to estimation: double tagging experiments are particularly useful to estimate tag-shedding rates. However, when these are not available, all sources of Type-I loss will be confounded and it will be almost impossible to discriminate among them, unless we are willing to make some restrictive assumptions.

The estimation of reporting rates is the most difficult issue, because of the multiple sources of error. For the specific case of the study of interactions, perhaps the question of estimating an absolute level of reporting is not critical, since we can estimate the level of interaction from the relative recoveries in fishery A and B, provided that we have an estimate of fishing mortality which was obtained independently from the tagging study. However, to do so we need to know (or assume) something about the relative levels of the reporting rates, i.e., what is the reporting rate in fishery A relative to the reporting rate of fishery B (NRC, 1994).

The key point here is that our perception of the level of interaction will be conditional on our assumptions about recovery rates. The problem is that there is little that we can do about it. To some extent, large rewards for recovered tags will improve the chances of the tag being reported. However, many of the tags are perhaps never seen, because the time for inspecting the fish is very short or because the tags might be detached and lost during the handling of the catch. If most of the recoveries of tags occur when the fish are processed, tag seeding experiments can provide an estimate. In such experiments a number

of fish are tagged after they were caught. Obviously, the situation is more complicated if most of the recoveries are made by the fishermen, since it is usually not possible to tag the fish caught without the fishermen being aware. If operational reasons are the main cause of tag loss, then we must be careful when the operational characteristics of the two interacting fisheries are very different, since it is likely that they will exhibit different reporting rates.

The processes behind Type-II tag losses are usually confounded as well. If we have a measure of fishing intensity (like fishing effort) that we can assume to be proportional to fishing mortality, we might possibly discriminate between removals due to the fishery and natural mortality and tag shedding. If we had double-tagging experiments then we might also be able to discriminate between natural mortality and a constant tag-shedding rate. This can be easily done, since tag shedding can be directly estimated from double tagging data. However, chances are that we will not have the necessary contrast in the data on fishing intensity to separate the effects of fishing and natural mortality. Moreover, any of these effects is likely to be confounded with the estimated exchange rates between fisheries.

Therefore, tagging experiments, in spite of being our best hope to quantify interactions, must be treated with caution and their sensitivities fully explored. In all cases, the possibility of better estimating the variability in levels of interactions can be improved upon by carrying out tagging experiments in multiple years. The question of reporting rates is likely to remain unresolved unless we can change drastically the way we recover the tags. An ideal (and, thus far, utopian) situation would be to design tags that could be detected at a distance by some passive device, like the pit tags used in salmon populations. If that proves unfeasible, perhaps some remedial (albeit expensive) measures can be implemented using port sampling programs, where the catch is inspected for undetected tags. If the conditions are standard and the fishery from which the catches originated can be established, a simple ratio between the tags returned by the fishery and the tags detected by the samplers can be used to determine relative reporting rates between fisheries.

Archival tags represent another potentially important source of data. Obviously, the possibility of obtaining information about the behaviour of the fish over a long period of time opens a large number of opportunities. Unfortunately, the high cost of the tags makes tagging large numbers of fish beyond most budgets. However, it might prove feasible for species with high exploitation rates for which we can expect numerous recoveries from a moderate number of tags released.

4.5 Identifying Interactions Using Studies on Stock Structure

Some of the research that can be done to assess the heterogeneity of the resource under exploitation can be carried out without direct information from the fishery. In any case, without knowledge of existing exploitation rates, we can only measure the potential for fishery interactions. Under this category, we encounter methods based on the biological characteristics of the resource. What we would like to measure here is the approximate degree of mixing of fish between different strata (areas, seasons, depths). If, for example, this mixing involves reproductive exchange, even at a minimal level, the population genetic structure will suggest that there is a single genetic population inhabiting both strata. If genetic markers indicate no reproductive exchange between strata, fishery interactions

between those strata are unlikely. However, these indications may be deceptive (see below).

Studying the stock structure of the resource using morphological information (meristics and morphometrics) has a long tradition in fisheries. The underlying hypothesis in these studies is that morphological differences reflect either differences in genetics or differences in the environment during early life development. More recent variations on this approach have included studies on the morphology of the otolith. They represent a relatively inexpensive way of studying the problem of stock structure, but they do not allow direct assessment of the genetic structure of the population. The latter can be accomplished using various approaches:

1) Allozyme frequency. In this methodology, results from protein electrophoresis analyses are used to construct a contingency table of gene frequencies that can be used to test the null hypothesis of homogeneity in the frequencies at different sampling locations. The problem with this analysis is that the test has low power and large sample sizes must be used in order to detect small differences.

2) Mitochondrial DNA (mtDNA). Allozyme frequencies reflect the nuclear genome inherited through recombination whereas mtDNA-based studies offer the advantage that the mitochondria are inherited only from the female parent. There is no recombination of mtDNA and it has a higher mutation rate (10^{-5} /year) compared with nuclear genes.

The mtDNA analyses are better suited to detect differences than allozyme analysis given the increased resolution of the analysis. Recent techniques based on nuclear microsatellite loci, which apparently has a mutation rate of 10^{-3} /year, seem to offer an even better resolution.

The main problem with genetic studies is that to say that one has found a different "stock" genetically is quite different from what fisheries scientists typically view as a stock. Indeed a reproductive exchange of one individual between two areas per generation is all that is needed to result in those areas containing a single genetic population. Yet such a low mixing rate would cause fishery scientists to view them as separate stocks (NRC, 1994). Also, recent genetic studies of billfish suggest the existence of reproductively-isolated stocks that are mixed in the fishing grounds.

A more promising approach is based on the analysis of otolith microconstituents. The theory behind this method is that the differences in the environment throughout the life of the fish are reflected in the chemical composition of the otolith. As such, they offer a view of the environmental changes that the individuals in the population have been through, and may indicate movements between areas with different chemical characteristics. However, the resolution of these techniques depends on the magnitude of the differences in the environment. The technology for detection of a large range of minerals has progressed substantially in the last decade (Ianelli, 1993), but we still need a better understanding of the processes leading to differences in the chemical composition of otoliths.

An important use of genetic techniques might be to estimate the stock composition of the catch to monitor the dynamics of reproductively-isolated stocks that are mixed in the

fishing grounds. This would involve sampling programs of a much larger scale than the studies discussed above. To date, no such program has been implemented. Such studies would be required if fisheries managers wish to ensure the conservation of each genetic population as well as each fishery stock.

4.6 Simulation as a Key Organisational Tool

Suppose that we have a collection (hopefully small) of possible mechanisms that could lead to interactions among identified components of a fishery. How can we organise these hypotheses in a way to better identify our data needs?

Perhaps one of the most useful tools that we have for that purpose today is simulation modelling. Uses of simulations are multiple, the one most commonly seen being the generation of artificial data to test the performance of some model or an estimation scheme (Sibert and Fournier, 1994, showed one such application). But more benefits can be derived from the use of simulations beyond testing the ability of a certain model to recover parameters. Simulations can be set up to assess the experimental design of tagging experiments under different hypotheses. The simulations can then be used to explore breadth and quantity of information that will be required to increase the power of the analysis and, especially, what will be required to reject certain hypotheses (see, for example, Bertignac, 1996). Simulations can provide the key element for the assessment of the power of different methods. Using a simulation, we can easily assess the likelihood of detecting or measuring a certain degree of interaction with a certain level of confidence. Forward simulations, or projections of the population also provide the flexibility of exploring different assumptions about recruitment.

In settings where the amount of data is reduced, simulations can be used to explore the alternative hypotheses that would give the same results and can be used to assess the costs and benefits of certain experiments or reducing uncertainty in certain key values. Therefore, simulations can provide guidelines for the future allocation of research resources. And simulations can easily be used to explore robustness of certain methods to violations of the assumptions.

Furthermore, a common experience in the use of simulations is that they improve our ability to understand and communicate the difficulties and constraints involved. Even if we do not have all the data required, a simulation exercise can help to establish what pieces of information are needed the most. The simulation analyses done by Kleiber and Baker (1987) or by Mullen et al. (1996) illustrate some of these points.

In summary, we need to expand the role that we assign to simulations. More than using them as tools to directly measure interactions, I foresee using simulations to identify the data collecting requirements that would enable us to reduce the range of possible hypotheses, and to identify the appropriate kinds of management actions.

5. STAGE TWO: OFFERING MANAGEMENT OPTIONS

Suppose that we have been fortunate and are confident of understanding the main processes governing some fishery interaction. That is, we have a credible model of how

the population and the interacting fisheries are related. The next step will be to consider what are the available management options.

It is difficult to discuss management options in a general context, since the goals often differ in the various situations. In some scenarios, the management objective might be the maximisation of long-term total yield. In other scenarios, it might be more desirable to preserve sources of employment or protein for small coastal communities and the distribution of the yield would take precedence over the simple maximisation of yield. Therefore, the assessment of the possible strategies has to be done in terms of the specified management objectives.

In cases where the recruitment to the population is not strongly dependent on the spawning stock biomass, yield-per-recruit analysis can provide a valuable idea of the trade-offs between different levels of effort exerted by the interacting fisheries (Miyabe, 1994). The simplest situation occurs where we have the same age-specific selectivities or partial recruitment in both fisheries. If that is the case, the distinction between fisheries is unnecessary from the point of view of the yield of the population. Most likely, this will not be the case and the pattern of age-specific selectivities will differ as a consequence of the different gears employed or because of different choices of temporal and spatial strata combined with a distribution differential by age. In those cases, different relative levels of effort between the fisheries will result in a different mean age of the fish in the catch. Assuming that we cannot control the age-at-entry in the individual fisheries, an appropriate management objective might be to find the relative levels of effort between the interacting fisheries that would result in the best yield-per-recruit. An alternative objective might result from consideration of the economic value per unit weight of the fish caught by the two fisheries. This could differ when the technology available to the different fisheries is different, or the ability to preserve the fish, or the processing or the markets are different.

If the situation is more complex, for example, where the fishing pressure of the interacting fisheries is sequential rather than simultaneous, projections using simulation models over long periods can be used to assess costs and benefits of alternative management strategies.

The value of learning more about the characteristics of the population might also be incorporated. Because we will often be facing uncertainties in the modelling of the fishery interaction, we need to consider adaptive management plans that could lead to learning, in the sense of reducing the set of alternative hypotheses. Such strategies manipulate levels of fishing effort to provide greater contrast for measuring the response of the system. The benefits of such learning can be assessed and compare with the costs of obtaining the additional information. Unfortunately, adaptive management strategies are often unstable policies, and do not create the best conditions for the resolution of the conflicts implicit in any interactions problem.

Whatever the method we use to assess the possible management scenarios, we will need to provide managers with a consequence of the options in the form of decision tables (Medley, 1994).

6. CONCLUSIONS: SOME PARTING THOUGHTS

Whenever we are faced with a problem, the range of options we can explore is set by the tools and the raw material available. These two elements are not necessarily additive; we cannot compensate for the absence of data by increasingly sophisticated analytical techniques. This problem is relevant to us, since in many of the management problems involving interactions, data will be a scarce commodity. Fortunately, our problem promotes good science: the better we can identify and assess the level of an interaction, the better chances we have of finding a resolution of the conflict that would be acceptable to all parties. Simply concluding that we do not have all the necessary information to assess an interaction is not going to diffuse the conflict.

Therefore, as it has been said many times, our first priority should be to establish sampling programs according to our needs. In most cases, this will involve tagging experiments. In those rare cases where most of the information has been collected, there are analytical methods already developed that can be applied. But even if methods were not available, the time and effort required to develop them would be a minor expense compared with the time required to collect new information. The specific pieces of information that will help us to solve the puzzle can be identified only after a careful consideration of the alternative explanatory hypotheses. That is why emphasis was placed on the role of simulations as tools to help in the design of vast, expensive experiments such as tagging programs. Too often, we have begun the analysis of tagging data only to realise that problems in the original sampling design impede our ability to narrow down possible explanations.

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UNRESOLVED PROBLEMS AND QUESTIONS FROM THE FIRST FAO CONSULTATION ON INTERACTIONS OF PACIFIC TUNA FISHERIES

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ABSTRACT

A review of the Proceedings of the First FAO Expert Consultation on Interactions of Pacific Tuna Fisheries reveals many unresolved issues. Important problems fall into several broad categories: 1) inadequate collection or analysis of fisheries data, 2) inadequate biological and ecosystem data to accurately model fishery interactions, 3) problems with tag and recapture experiments, 4) lack of alternative methods for quantifying fish movements, and 5) a narrow view of fishery interactions. Potential suggestions for action include: 1) improve basic fisheries data collection and stock assessment, 2) expand and improve tag and release programs, 3) develop new methods for tracing fish movements, and 4) simulate best-case and worst-case fishery interaction scenarios and economic impacts for the purposes of risk assessment and discussions of resource allocation.

1. INTRODUCTION

A goal of the first two fishery interaction consultations was to assess the extent and severity of impacts resulting from sequential fishing by several fisheries on the same (or dependent) resources. The purpose of this paper was to present outstanding issues and problems remaining from the previous consultation (see Shomura et al., 1994). These problems and shortfalls hinder the estimation of fisheries interactions. Questions were posed to trigger discussion. Section 7 of the summary report from the second consultation (Shomura et al., 1995) covers the responses of the consultation participants.

The perspective set by the first consultation was that important issues are those with practical relevance to fisheries management. This perspective was maintained here. As noted in Section 7.1 of the summary report (Shomura et al., 1995), many critical and recurrent problems (i.e., inadequate fishery statistics, inadequate biological and ecosystem data, problems with tagging) are very similar to those in stock assessment research. If such problems prevent the estimation of fishery impacts on a resource (i.e., stock assessment), those same problems can prevent the estimation of fishery interactions among users of the resource. Most of the problems and information gaps have been clearly and thoroughly described in the proceedings of the first consultation and in numerous workshops and symposia on fisheries management. In the interim between the first and second consultations, researchers have done an excellent job of focusing on relevant issues, but many problems and shortfalls remain.

2. PROBLEMS AND QUESTIONS

Many of the problems and issues were perennial and very familiar to participants of the second consultation, which may have inhibited lively discussion. Prior to the consultation the participants were asked to identify issues that had been adequately addressed or problems that had been truly solved, but none did so. It seemed to be unanimous that better information is needed in almost every situation. Realistically, choices must be made regarding priorities for further work. Each problem described below is followed by a trigger question regarding that problem. To provoke discussion and prioritization, the questions were often phrased as choices between alternatives.

2.1 Inadequate Collection or Analysis of Fishery Data

Problem 1: Species targeting, gear characteristics, and gear efficiency are often inadequately described or quantified. The solution to this problem involves a much greater emphasis on the collection of more and better fisheries statistics. However, recent attempts to standardize purse seine catch-per-unit-effort (CPUE) data in the western Pacific have proven to be discouraging and it has been suggested that such attempts may be futile (Anonymous, 1994).

Question 1: Are meaningful measures of relative abundance possible through the collection and analysis of catch and effort data? For some or all fishing methods, are CPUE indices hopelessly confounded by changes in fishing strategy, technique, and other fishery performance factors so that they cannot be corrected to represent fish abundance?

Problem 2: Small scale commercial, artisanal, and subsistence data for many fisheries do not exist or have only recently been collected. Projects have been initiated to retrieve and analyse historical data from such fisheries (He and Boggs, 1996), but useful results have sometimes been obtained quickly and economically through analysis of existing tag recapture results and simulation (SPC, 1994).

Question 2: How much effort should be expended to recover useful historical data from localized, small scale or artisanal fisheries? Is it more practical to focus on improving current statistics and to model interactions in such fisheries based on tagging experiments?

Problem 3: Better species identification, and more (and better) size data are needed from fishery data collection programs.

Question 3: What are the most important categories of fishery data that are not being collected adequately? Assuming similar levels of research funding, what activities could be viewed as less important?

Problem 4: Many Pacific tuna stock assessments are tentative and inconclusive. Spatial distribution, fish movements, and fish size distribution need to be incorporated in assessments.

Question 4: What are good examples of adequate tuna stock assessment, and what additional data are most needed to conduct such assessments for tuna stocks in the Pacific?

Are we limited mostly by insufficient information or are access to the data and a lack of human resources to do the work equally important?

Problem 5: In many areas the fisheries statistics available to any one nation or agency are incomplete due to confidentiality rules that prevent the release of data or that require aggregation of data into a summary form that hinders useful analysis. Confidential data may often be exchanged through the establishment of specific collaborative research projects between nations or agencies. However, no comprehensive program exists to enable mutual exchange or centralized compilation of detailed fishery statistics from all major Pacific tuna fishing nations.

Question 5: Would the establishment of a regional monitoring and management authority to exchange data on all tuna fisheries throughout their range speed up the assessment of stocks and the quantification of fishery interactions? Alternatively, is the current practice of arranging collaborative data exchanges to accomplish specific research goals adequate and appropriate given the very limited human resources available to conduct the needed analyses?

2.2 Inadequate Biological and Ecosystem Data

Problem 6: Although the importance of discriminating between stocks is obvious, the practical meaning of genetic stock structure studies conducted to date is unclear. Lack of genetic differences between groups does not necessarily imply that a single stock should be assumed for management purposes. For example, a lack of genetic heterogeneity between areas (i.e., between fish from the Atlantic and Pacific Oceans) implies that there is a single genetic population. However, movement of a few fish per generation between these areas can produce genetic homogeneity. When gene flow is substantial but few fish actually move between areas, separate management is justified. Conversely, observation of genetic differences between groups does not necessarily imply that separate stocks should be assumed for management purposes. A number of mechanisms (e.g., spawning site fidelity) may contribute to geographic heterogeneity in genotypes even when substantial movement of fish between areas is documented. Although genetic researchers do find geographic differences, few recommend actual population boundaries for stocks because the geographic resolution of their work is usually limited to a handful of locations and because the practical implications of their results are vague. Before much larger scale genetic studies are conducted researchers should clarify the meaning of results of such studies.

Question 6: What is the relevance of genetic studies to the question of whether or not separate fisheries exploit a common resource? What testable hypotheses relevant to fishery management can be generated from existing data? Could hypothesis testing be conducted on more tractable populations as a proxy for tuna?

Problem 7: Various growth rate estimates exist for tunas from different parts of the Pacific. Differences are found between growth rates estimated by analysis of modes in size-frequency distributions and growth rates based on otoliths or other hard parts. Differences are also found using similar methods in the same area. Still, growth rate estimates are probably much less variable than many other parameters used in stock assessments. Much emphasis is placed on the importance of size-frequency data in the

more sophisticated stock assessments and analyses of fishery interaction, and collection of more and better size data has been recommended. These data are important and useful without independent estimates of growth rate. However, resolving the differences among independent growth rate estimates would allow stock assessment and fishery interaction models based on size-frequency data to be constrained in useful ways (e.g., by ruling out faster or slower growth rates than those resulting from hard part studies).

Question 7: Should growth rate studies receive much further attention, or are the differences between methods and areas acceptable given the poorer quality of information on other vital rate statistics?

Problem 8: Natural mortality is wrongly assumed to be independent of fish size. In tagging studies natural mortality is estimated from the decline in tag recoveries over time (i.e., total mortality) under different levels of exploitation (i.e., fishing mortality). However, natural mortality is difficult to distinguish from fish movement away from fished areas. Moreover, differences in natural mortality with fish size are difficult to estimate because in comparison with small fish, large fish are more difficult to tag. Also, large fish may have different vulnerabilities to capture and different movement patterns from small fish. Size-specific differences in natural mortality could be especially important when fishery interaction models based mostly on tag results from small fish are extrapolated to whole stocks. Some fisheries are highly dependent on larger fish, and the modelled effects of fishery interactions on such fisheries could be erroneous.

Question 8: How can natural mortality and total mortality of older tunas be estimated? How sensitive are fishery interaction models to size-specific differences in natural mortality? Can we assume that the differences are so small, or that the models are so robust, that the problem may be ignored?

Problem 9: For most tuna stocks, little is known regarding the ecological causes of variation in abundance among age classes. Cannibalism, interspecific predation, competition, and trophic dynamics probably affect recruitment, growth, reproduction, and mortality of tunas. For some stocks it has been hypothesized that strong year-classes occur in alternating years or that strong year classes accompany or follow major environmental perturbations, but the biological mechanisms for such relationships are not well known. Generally, single-species models are used for stock assessment and interactions analyses. The number of unknown ecosystem variables is too great for ecosystems models to have had much practical application to fishery interaction problems. A definitive study of the food web dynamics of the pelagic ecosystem would be a massive undertaking.

Question 9: Do priorities dictate continued deferment of multispecies ecosystems approaches to explaining the dynamics of the exploited resources, or are there particular fisheries and stocks where such methods could be practically applied?

Problem 10: To detect and quantify the impacts of fishery interaction against the background of natural variability, we will need a better understanding of the effects of oceanographic variation on fisheries. Oceanographic studies, especially those utilizing remote sensing technologies combined with ocean circulation models, are needed to explain variation in fishery performance, allow closer estimation of trends in fish abundance, and

permit better analyses of fishery interaction. However, the mechanisms linking oceanographic variables to tuna abundance, distribution, and catchability are probably trophic, complex, and potentially chaotic. It may be that substantial natural variation in abundance, distribution, and catchability will remain unexplained and fishery interactions will remain difficult to detect or quantify. Many efforts to quantify the effects of fishing intensity on fish abundance may continue to treat natural variation as noise.

Question 10: If fishery impacts on stocks are so small relative to natural variations that the fishery impacts cannot be detected, then are the fishery impacts very important? Natural variations in abundance may exhibit more noise and less trend than fishing power or species targeting. The latter tend to exhibit coherent trends that oppose and mask declines in abundance. Would it be more practical to direct our efforts to ensure that fishery data adequately quantify a useful standard of fishing effort than it would be to try to account for natural variability in fish distribution and abundance?

2.3 Problems With Tag and Recapture Experiments

Problem 11: The low rate of yellowfin tuna tag recoveries from longline gear compared with surface gear suggests that there could be a segregation of fish between deep and shallow habitats at some stage of life. Analysis of the sparse returns of yellowfin in the larger size groups important in the longline fishery suggests that the returns from this fishery are lower than expected. Biological studies may shed some light on this issue by indicating other differences between surface- and subsurface-caught yellowfin tuna. However, more tagging data on large tuna of all species would be useful for many reasons, including the estimation of size-specific mortality. Research longline fishing indicates that large tuna caught by longline gear can be tagged and recovered, as can large tuna caught by recreational fishermen.

Question 11: Could the tagging of thousands of large tuna ever be practical? Would a cooperative program involving the agencies conducting research longline operations together with recreational fishermen be able to tag and release useful numbers of large tuna in the Pacific?

Problem 12: The trivial rewards given to those who recapture and report tagged fish probably contribute to a low reporting rate of recaptures. Although assessments are robust to non-reporting as long as the rate is somewhat stable, the effectiveness of tagging programs is diminished in direct proportion to non-reporting. A clear outcome of the previous consultation was that tagging programs were among the most effective means of studying fishery interaction. Such programs are so costly that it would seem to be relatively cost-effective to increase the rewards offered for tags, or to make greater use of lotteries for those who report tag recoveries.

Question 12: Should the consultation recommend that a fund and/or a cooperative program be established to increase the rewards offered for tag returns?

Problem 13: More work is needed to characterize the statistical properties of estimates of fish movements based on tag return data using the various models that have been devised for that purpose. The previous consultation strongly recommended that the same tag return

data be analysed using several of the existing models to explore differences due to technique. Additional analyses are needed to examine how stable apparent patterns of directed movement may be from one time period to another. Although most tagging programs are too expensive to continue indefinitely, existing results should be closely examined with regard to time trends in directed components of movement. It may be that diffusive components of movement are more consistent than directed movements, and that movements that appear to be directed in individual years are actually more random when analysed in aggregate over many years. Perhaps only directed movements which are demonstrably repetitive should be used in simulations of interaction between geographically separate (or partially overlapping) fisheries.

Question 13: Are the movement patterns determined from tag-recapture experiments reproducible when analysed using different models? And are the patterns repetitive over time? In fishery interaction simulations, might it be useful to use both the observed pattern of tuna movements as well as an alternative pattern in which the directed components are made random (i.e., the directed components are not repetitive over time)?

2.4 Lack of Alternative Methods for Quantifying Fish Movements

Problem 14: Alternative methods are needed to survey the movement patterns of tuna that are difficult to tag in large numbers, and to document movements in areas where tuna are seldom caught. Tag and recapture experiments have proven to be invaluable in the study of fishery interaction, but there remain aspects that have been difficult to address using this technique, such as the movements of larger tuna, the possible segregation of yellowfin tuna by depth, whether or not observed directed movements are repetitive, whether they are segments of true migrations, and what sort of movements may be under-represented as tuna enter areas where fishing is not intense or vulnerability to fishing gear is reduced.

More tagging experiments are needed in a host of locations and fisheries, yet the cost is daunting. The largest and most useful tagging programs have been directed towards the most easily tagged species and sizes of tuna but have nonetheless been quite expensive. Cost-effective alternatives to large-scale tagging experiments would be very useful. However, tagging experiments have the dividend that they also allow the estimation of mortality, whereas the existing alternative approaches to studying movements do not.

Alternative methods of studying fish movements include surveys that map changes in observed abundance (e.g., visual, video, acoustic, laser, and radar surveys) and methods that track individual fish (e.g., sonic tracking and archival tags, Problem 15 below). Some of the survey methods might be used to follow individual tuna aggregations or to measure instantaneous movement vectors. More often, the survey methods rely on the assumption that fish move as the patterns of high abundance move, whereas the patterns may simply reflect aggregation and dissipation of fish due to other processes.

Question 14: Are there any promising new technological developments that suggest feasible survey methods for documenting tuna movements? Considering the benefits of conventional tagging studies as well as their high cost and limitations, could any of these survey methods be more cost-effective than tagging programs?

Problem 15: Alternative methods for documenting tuna movements through the study of individual fish are needed. Sonic tracking of individual fish is generally too short in duration to provide useful data on long-term movements. This method could be useful for observing behavioural segregation of large yellowfin tuna into either the deep or the shallow zones exploited by longlines or purse seines (respectively), but would not indicate when the habitat segregation originated or how vulnerable each type of yellowfin might have been to different fisheries at an earlier stage in life (i.e., type B interaction of Hampton, 1994). Moored arrays of hydrophones could be useful in monitoring longer-term migrations of tuna tagged with individually recognizable transponders, but the arrays would have to be huge. Alternatively, tuna could carry archival tags that would store movement data while out of the range of moored hydrophones. Archived data would be downloaded when the fish encountered one of the widely scattered moorings. Archival tags appear the most promising as a method of recording long-term movements, but because tag recapture rates are very low for most species, a fishery-independent archival tag data recovery system may be required.

Genetic and chemical studies of individual fish might also provide valuable information on past movements or origins of tuna. If spawning site fidelity exists, genetic tests might indicate the origins of fish. Alternatively, the absence of movement between broad areas might be established by reliable classification of individuals into geographically distinct genotypes (but see Problem 6). Chemical microconstituents concentrically deposited in otoliths could be so site-specific that their sequence might reveal an origin and history of movement. Alternatively the microconstituents may be so dependent on a multitude of variables (i.e., food and temperature) as to be undecipherable.

Question 15: Are there promising new technological developments that may allow tracking (or backtracking) of individual fish movements over the long term? Again, considering the benefits of conventional tagging studies as well as their high cost and limitations, could any of these methods be more cost-effective than tagging programs?

2.5 Narrow View of Fishery Interactions

Problem 16: Fishery interactions studies have mostly focused on marginal interactions rather than on absolute interactions (Kleiber, 1994), which may have minimized the apparent magnitude of fishery interactions. Marginal interaction is the effect of variations in the intensity of one fishery on the performance of another, whereas absolute interaction is the sum effect of the existence of one fishery on the performance of another (Kleiber, 1994). Because variations in fishing effort are generally much less than the total fishing effort by an entire fishery, marginal interactions are likely to be less intense than absolute interactions. For many fisheries reliable data may exist only for recent times (or not at all). In other cases traditional fisheries no longer exist, and it is not known whether or not fishery interaction contributed to their demise.

Data on the performance of subsistence or artisanal fisheries before the large, distant water fisheries became established almost never exist, so that empirical detection of absolute interaction is unlikely. Declines in the apparent abundance of tuna characterized the development of longline fishing in the Pacific, as was to be expected as the level of exploitation increased. One way to address absolute interaction in such cases is through

simulation, as was recently done for the fisheries of Kiribati (SPC, 1994), where the effect on local fishery performance of eliminating the entire Pacific purse seine fishery was explored.

Question 16: Should greater attention be given to estimating absolute, rather than marginal interaction, especially in the case of interactions between very large fisheries and artisanal or subsistence fisheries?

Problem 17: The importance of detecting fishery interactions even when the interactions are small was discussed at the previous consultation. It was suggested that finding and quantifying such interactions were important in order to be able to predict larger interactions that could occur as fisheries expand. However, predicting larger interactions at increased levels of effort based on poorly quantified relationships at lower levels of effort may be misleading.

Question 17: When a fishery interaction is not clearly evident and likely to be weak, how appropriate or valuable is it to search harder for empirical evidence of the hypothesized interaction? How useful is a projection based on empirical evidence of a small interaction? If the concern is over a larger interaction that may occur at higher effort levels, why not allow the fishery to grow until such an interaction becomes clearly evident?

Problem 18: At the start of the first consultation, the participants agreed that fisheries economics issues were beyond the scope of that meeting. Economic studies, however, remain extremely relevant to the study of fishery interactions. Fishery interaction issues often arise well before the population of the exploited resource is threatened, and while the risks and benefits of management alternatives are more economic than biological. When population stability is not the issue, assessment of the risks involved in allowing one fishery to expand at the detriment of another should emphasize the economic costs and benefits of each type of fishing. Furthermore, market interactions between fisheries (as commodity suppliers) may be more easily detected and quantified than resource-mediated (biological) fishery interactions.

Question 18: Should greater attention be given to the economic interactions between tuna fisheries as well as the economic costs and benefits of tuna fisheries?

3. CONCLUSIONS

The participants' reactions to the trigger questions (see Section 7 of the summary report, Shomura et al., 1995) may reflect a much broader understanding of the problems and issues than those of this author. Nevertheless, I offer the following preliminary generalizations (in advance of the second consultation).

Fishery data collection activities must be expanded and improved. Such activities are old-fashioned, rarely provide results publishable in peer-reviewed literature, and are not considered to be research by the academic community. These activities are essential, however, to evaluating fisheries interactions. Understanding of oceanographic and ecological factors affecting resource dynamics and fishery performance may be greatly improved, or these factors may remain poorly understood sources of noise. Either way,

measures of fishery performance based on fishery data will continue to be essential in evaluating the need for management. The most important requirement for fishery data collection, beyond defining the scale and location of each fishery and the species and sizes of fish caught, should be to provide measures of fishery performance that account for changes in fishing power, gear efficiency, and targeting.

Tag and recapture experiments have proven to be very valuable and complementary to analyses of fishery statistics in identifying and quantifying fishery interactions. No other research method has provided as much useful information or has been the basis of so many practical applications in this field. However, there are very important issues involving fisheries for larger tuna for which tagging experiments have fallen short of success. A major effort to tag larger tuna should be initiated, or alternative methods for measuring the movements and mortality rates of larger tuna must be developed. Simulations may provide the best means of resolving fishery interaction issues. Reasonable upper and lower bounds of possible movement rates, and natural mortality, along with the best available fishery statistics, should be used to simulate each potential interaction. Economic information should be used to assess the risks implied by the best- and worst-case simulations, to explore the consequences of allocation alternatives, and to assess the potential benefits of regulating the fisheries.

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MULTI-SPECIES AND MULTI-GEAR TUNA FISHERIES IN THE ATLANTIC AND POSSIBLE INTERACTIONS BETWEEN GEARS AND SPECIES

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ABSTRACT

Most of the tuna fisheries in the Atlantic Ocean (including the Mediterranean Sea) often target more than one species, with additional species being taken as bycatch. These multi-species fisheries are very complicated; one species is targeted by various fisheries simultaneously or consecutively, while the same species is also caught by a third fishery as bycatch. Also, the Atlantic tuna stocks are quite heavily exploited; gear interactions are possibly more significant than for those stocks which are less exploited. In this report, the type and magnitude of possible gear interactions on Atlantic (and Mediterranean) tunas and related species are briefly discussed. The fisheries are considered in terms of longline and surface gears, with some reference to the probable interaction among surface gears. This report analyses possible fishery interactions on size-specific tuna catches as well as in terms of area. As far as yellowfin, skipjack and swordfish are concerned, the interactions between longline and surface gears do not appear to be as significant as has been believed. On the other hand, for albacore and bluefin tuna, fishing mortality by surface and longline fisheries seems to occur in different size categories of fish, suggesting possible significant interaction.

1. ATLANTIC TUNA FISHERIES

The following are the major tunas and tuna-like species that are targeted commercially by the Atlantic[1] tuna fisheries: bluefin tuna (*Thunnus thynnus*), southern bluefin tuna (*T. maccoyii*), yellowfin tuna (*T. albacares*), bigeye tuna (*T. obesus*), albacore (*T. alalunga*), skipjack (*Katsuwonus pelamis*) and swordfish (*Xiphias gladius*). In addition to these species, many small tunas and tuna-like fishes are of importance to coastal fishermen, from the point of view of economy as well as diet. These species are mainly blackfin tuna (*T. atlanticus*), various king mackerel species (*Scomberomorus* spp.), bonito (*Sarda sarda*) and frigate tunas (*Auxis thazard*). Among billfishes, sailfish (*Istiophorus albicans*) are targeted by many east Atlantic coastal fisheries but other large billfishes are either bycatch species to the commercial fisheries or targeted by recreational fishermen. Atlantic (including the Mediterranean Sea) catches of tunas and tuna-like species are summarized in Table 1.

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[1] According to the Convention on which the International Commission for the Conservation of Atlantic Tunas (ICCAT) was established, the Atlantic Ocean includes all the adjacent seas including the Mediterranean. Some stocks are common between the Atlantic and the Mediterranean Sea and, hence, in this report the Mediterranean Sea is considered to be a part of the Atlantic Ocean.

Table 1. Total Atlantic (including Mediterranean Sea) tuna catches (in metric tons) by species, 1983-93 (as of 12 July 1995).

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
Bluefin tuna	24202	26716	26836	22828	20668	27280	24874	24890	27051	27264	29674
Southern bluefin tuna	522	1636	1493	426	1193	612	700	1257	1344	525	1576
Yellowfin tuna	162315	113166	149110	134539	135326	127964	155287	177134	158586	148442	142874
Albacore	67320	57661	75978	88469	82707	67866	63365	67195	53723	66442	72985
Bigeye tuna	60339	69208	74093	59412	48868	58512	69295	71415	71702	77497	89645
Blackfin tuna	1738	1908	1403	1875	2130	3134	2918	3715	3542	4103	3460
Atlantic black skipjack	20881	19829	11699	13426	14439	22916	24272	25050	20014	16507	4667
Skipjack	133681	126786	118670	124473	116577	139888	115386	139639	195439	145702	180434
Bonito	42874	22505	25433	21990	30229	40886	26164	28049	33832	21944	29021
Frigate tuna	20221	25343	22460	17907	19578	20724	17473	16169	10639	7755	4251
Bullet tuna	0	0	0	2	0	357	723	3634	2171	814	70
Plain bonito	38	49	133	87	564	1482	1116	335	408	363	344
Wahoo	2366	2159	920	1150	1235	1616	1546	1460	1641	1912	2281
Spotted Spanish mackerel	16206	19491	15091	20666	20743	19518	21860	16960	17757	18326	20006
Serra Spanish mackerel	0	0	0	0	0	2704	2864	2471	2749	0	0
King mackerel	14607	13182	9964	12187	11890	13041	10841	10171	10122	10536	8994
W. African Spanish Mackerel	4716	4498	3989	3292	1799	3772	2684	4248	3581	1433	1788
Cero	677	680	574	500	392	219	234	225	375	389	360
King mackerel, unclassified	20	485	22	11	102	159	37	80	176	305	265
Sailfish	3780	3121	2925	2709	3112	2485	1967	2407	1994	2403	2877
Spearfishes	0	0	0	54	75	10	40	1	0	0	0
Black marlin	1	6	2	16	++	0	26	2	5	0	7
Blue marlin	1801	2227	2694	1954	1870	2497	3743	3293	3045	3060	2826
White marlin	1694	1089	1531	1630	1466	1283	1672	1035	1745	1451	1137
Swordfish	26702	35540	39104	41021	43730	51693	51671	42866	38742	40279	43689
Billfish, unclassified	21	161	156	138	252	178	127	35	28	43	5
Mixed tuna	0	0	0	0	0	0	0	0	0	0	3
Others & unclassified	11870	7554	7411	6728	14722	12435	14807	16832	16433	23808	7645
Total	618592	555000	591691	577490	573667	623231	615692	660568	676844	621303	650884

There is no fishing gear which catches one of the above species exclusively. In other words, all the tuna fishing gears also catch various tuna-like fishes in addition to their target species. At the same time, there is no tuna species which is the exclusive target of a single fishery (or fishing gear). Therefore, when considering fishing effort and abundance indices, the possibility of the existence of species interaction as well as gear interaction must always be taken into consideration. This situation is very similar to that of any other ocean in the world, but since the tuna resources in the Atlantic have been extensively exploited by European, African, American and Asian nations, and by the local subsistence fisheries as much as by the distant water high seas fishing nations, gear interaction is probably more complicated and significant.

Table 2 shows the catches of the commercially important tunas and tuna-like species, by major fishing gears in the Atlantic, in 1993. This table explicitly shows the complications of tuna fisheries in the Atlantic. What is not shown in the table is the catch of minor species such as frigate tuna, bonito, etc. As a matter of fact, these species are often discarded at sea and are never reflected in the catch statistics; this is particularly true of large industrialized fleets. On the other hand, as indicated above, the catches of such minor species are still very important for subsistence fishermen who catch these species with very small boats (e.g., dugout canoes).

Table 2. Catches, by species, of the major fisheries and areas in the Atlantic Ocean, 1993, in thousands of metric tons.(BFT=bluefin tuna, ALB=albacore, YFT=yellowfin tuna, BET=bigeye tuna, SKJ=skipjack tuna, SWO=swordfish)

Major gears	Area	BFT	ALB	YFT	BET	SKJ	SWO
Purse seine	E. Tropical Atl.		0.4	100.8	17.0	80.5	
Baitboat	E. Tropical Atl.		++	13.3	12.3	40.3	
Longline	E. Tropical Atl.			4.3	24.6		
Purse seine	W. Tropical Atl.		0.2	11.2	0.1	3.3	
Baitboat	W. Tropical Atl.			5.2	0.0	21.4	
Longline	W. Tropical Atl.			9.4	16.0		
Baitboat	Northeast Temperate	2.4	13.6				
Longline	Northeast Temperate	2.6					
Troll	Northeast Temperate	0.3	8.7				
Drift net+Pelagic trawl	Northeast Temperate	2.7	5.9				0.9
Longline	Northeast Temperate	4.6	1.9	1.8	7.3		7.5
Purse seine	Mediterranean	11.8					
Baitboat + other surf.	Southeast Temperate		4.6				0.4
Longline	Southeast Temperate		10.9	2.5	17.3		6.5
		0.6					
Purse seine	Northwest Temperate	0.3					
Other surface	Northwest Temperate	0.8					0.4
Longline	Northwest Temperate	0.8	2.0	3.4	8.0		7.1
Baitboat + other surf.	Southwest Temperate		0.8				0.1
Longline	Southwest Temperate		11.0	6.0	8.0		7.6

2. STOCK UNITS OF MAJOR SPECIES OF TUNA AND THEIR EXPLOITATION

Figures 1-10 show average catches (in weight) of bluefin, yellowfin, albacore, bigeye and swordfish for the period of 1983 through 1993, by 5° x 5° area, by quarter, and by surface and longline gears. The size of the circles is proportional to catch and the same scale was used for longline and surface gears, so that these figures can be used to compare catches directly. However, different scales are used among species and, therefore, the circle sizes between species can not be compared directly. Efforts with nil catch are not shown in the figures. When catches were reported only in number of fish, they were converted into weight using constant conversion factors. No consideration was given to the variability of sizes between seasons, years and areas for this analysis, since the figures only show the indication of catch levels on a large scale basis. A few minor fisheries, for which information on area-time distributions of catches is not available, are excluded.

The surface gears contain all gears other than longline. Therefore, many gears (fisheries) are combined in this category. Although comparisons of average catches by longline and surface gears show a possible existence of gear interactions, gear interactions may also exist among various surface gears. On the other hand, the catches in the same area by surface and longline gears do not necessarily indicate the presence of simultaneous gear interactions, since these could be on different stocks or different age classes. The reverse is also true, i.e., the non-overlapping fisheries could have interactions.

These figures are prepared on a quarterly basis, since some of the overlapping between longline and surface fisheries on an annual basis may not show the true overlapping which takes place on a seasonal basis.

A general overview of the consideration of stock structure and fisheries interactions is provided below for major commercial tunas and tuna-like species in the Atlantic.

2.1 Bluefin tuna (Figures 1 and 2)

The ICCAT has adopted a two-stock hypothesis for Atlantic bluefin tuna, one stock in the east (including the Mediterranean) and one in the west, with some unknown (but of not very significant) magnitude of annual mixing between the two. These stocks are harvested at age 0 to 1 by handline (Spain and Italy), trap (Spain and Morocco), drift gillnet (Italy) and purse seine (Spain); at age 2-4 by baitboat (Spain), purse seine (France, Spain and USA), troll lines (Spain and considerably less by France), rod and reel (Spain, USA and France), handline, drift gillnet and trap; at age 6 and above, by longliners (Asian, USA, Canada and many other boats flying flags of convenience), harpoon (Italy, Canada), tended line (Canada), trap (Spain, Morocco and Canada), purse seine (France, Italy and Spain), handline (Spain, Morocco, Portugal) and rod and reel (USA).

Figures 1 and 2 demonstrate very little overlapping in the geographical distribution of bluefin catches between longline and surface gears. However, both are definitely fishing on the same stock directed at different age groups, and the geographical distributions of bluefin tuna change according to ages. The interactions between surface gears and longline alone could be complex, since most of the surface gears catch juveniles and, hence, will

probably have an effect on longline catches a few years later, while the same size is caught by both trap and longline which are, therefore, directly competitive.

For the eastern stock, interactions among surface gears alone could be significant, since each fishery takes specific age groups in specific areas from age 0 to 10+, although quantifying the interactions would be very difficult due to the lack of fundamental data.

On the other hand, fishing by various surface gears for the same age groups also occurs almost in the same area and at the same time (e.g., troll and baitboat for age 2-4). The situation is further complicated by many of these gears catching tunas other than bluefin (e.g., Spanish trollers catch albacore as the target species; Asian longliners also target bigeye and most of the other tunas and Spanish longliners target swordfish).

2.2 Yellowfin tuna (Figures 3 and 4)

In the past, ICCAT has based its stock assessments on a two-stock hypothesis, i.e., one stock in the east and one in the west. However, due to the large number of recoveries of yellowfin tagged in the west and recovered in the east, the Commission is now inclined to adopt a one-stock hypothesis. However, further tagging and its analysis would be needed in order to draw any conclusions, since the fishing mortality rate seems much lower in the west, which may explain the lack of recoveries of tags in the west. The size of the fish being tagged should also be taken into account in such an analysis.

Small yellowfin tuna (age 0 to age 1) are caught mainly in the east tropical Atlantic by purse seine (mostly France, Spain, Morocco and vessels flying flags of convenience) and baitboats (Spain, Senegal, Ghana, etc.).

Medium to large size yellowfin are caught in both the east and west by longline (Cuba and Asian countries, particularly Korea), purse seine (France, Spain, Venezuela), baitboat (Portugal, Spain, Cape Verde, Venezuela). Most of the surface fisheries (baitboat and purse seine) also target skipjack, while the longliners target other major species of tuna.

As shown in Figures 3 and 4, the longline catches have declined in recent years. Although the major reason for this decline is the change in target species of longliners from yellowfin to bigeye, the surface catches can have an impact on the yellowfin population available for longline fisheries but not the other way around, particularly given that no spawner-recruitment relation has been recognized (also see the discussion in Section IV).

2.3 Albacore (Figures 5 and 6)

Two stocks, one in the north and one in the south, have been hypothesized based on the distribution and spawning areas. South Atlantic albacore may have some mixing with the Indian Ocean stocks.

The northern stock is harvested by surface gears and longline, while the catch by the latter has been much less important. The fishing area does not overlap significantly between these two types of gears due to the fact that the surface gears catch mostly young fish while the longline catches spawning stock (or mature fish). The surface gears consist

of troll (Spain and France), baitboat (Spain, France), drift gillnet (France, Ireland and the UK) and mid-water trawl (France), and the areas of their operations are almost identical. In recent years, there has been significant conflict between the countries using drift gillnets and those which prohibit the use of this gear, since it seems that the drift gillnet is a more efficient fishing method (see Section 3.3 for explanation). Yield-per-recruit studies suggest that some increase in yield could be expected if the size of the first capture is increased.

The southern stock has been taken by purse seine (South Africa) as a target species as well as bycatch to yellowfin tuna (France and Spain), during the juvenile stage. However, the major exploitation is by longline (Taiwan) on the spawning stock. This is a rather unique tuna stock, on which both gear and species interactions are suspected to be minor, since most of the catches of southern albacore are taken by Taiwanese longliners strictly targeting albacore.

2.4 Bigeye Tuna (Figures 7 and 8)

A single stock in the total Atlantic is assumed. The young fish (0 to 2 years) are caught in eastern tropical waters by purse seine (France and Spain) and baitboat (Ghana). Medium to large bigeye continue to be caught by purse seine (France and Spain), but more specifically by the longliners (Japan, Korea and Taiwan) targeting this species. The purse seine and baitboat fisheries for juveniles actually catch a mixture of yellowfin, skipjack and bigeye, and report them together as skipjack or small tunas. Therefore, the total catches by species are not reported. The species breakdown of these mixed catches of small fish have been estimated by the intensive sampling of catches.

Since the magnitude of the longline catches has been much greater than those of surface gears, the recent increase in catches of small bigeye by surface gears may have a strong impact on the longline catches in the future, particularly in light of the results of the yield per recruit analysis, i.e., a substantial increase in yield is expected if the age of first capture is increased. It should be noted that the fishing areas significantly overlap between these two categories of gears in eastern tropical waters. However, the effect of longline fishery on surface gears would be minimal, unless the longliners were to deplete the spawning stock and so affect the abundance of juveniles, which has not been the case.

2.5 Skipjack Tuna

The two-stock hypothesis, east and west, has been adopted by ICCAT. Gear interaction is probably minor and less complex for this species, since longline gears are not involved. Also the fisheries harvesting this stock are limited to baitboat and purse seine.

In the southwest Atlantic, skipjack are almost entirely harvested by baitboat (Brazil). Occasional purse seine fisheries took place in the past but they have not been very successful. In the northeast Atlantic, baitboat and purse seiners (both Venezuelan) harvest this species together with yellowfin tuna.

In the east Atlantic, both purse seiners and baitboats (Ghana, France and Spain) catch large quantities of skipjack tuna. However, it is very difficult to evaluate the effort exerted on skipjack since this fishing effort is generally directed towards yellowfin tuna. This is

particularly obvious for the purse seine fleets, except for certain years and areas when some purse seine fleets (particularly that of Spain) gave priority to skipjack. Hence, the situation is quite complicated.

2.6 Swordfish (Figures 9 and 10)

Stock structure is not yet very well defined. For the time being, the stock assessments are carried out under various hypotheses, North Atlantic, South Atlantic, and Mediterranean, or the entire Atlantic and Mediterranean. The majority of the catches are taken by longline targeting swordfish (Spain, Canada, Brazil, Portugal, Italy and many other Mediterranean countries), while some drift gillnet (Italy) and harpoon (Italy) fisheries also take place (particularly in the Mediterranean).

The Asian longliners (Japan and Taiwan) consider swordfish to be bycatch. However, in terms of quantity, the catch of this species is too large to be considered as bycatch. Swordfish catches comprise close to, or sometimes exceed, 10% of the total catches of longline fishery targeting bigeye. This is because the geographical distribution areas of bigeye and swordfish coincide, although vertically the bigeye is fished at a depth while swordfish are caught nearer the surface.

3. HISTORICAL CHANGES IN GEAR INTERACTION

As the fisheries develop, there can be considerable changes in gear interactions on tuna stocks. These changes have been seen for almost all the tuna species. The extreme cases of bluefin, yellowfin and albacore tunas are briefly discussed below:

3.1 Bluefin Tuna

For the eastern stock, the major catches have been in surface gears. The interactions among surface gears should have been significant as described briefly in Section 2.1, but the magnitudes may vary historically, depending on the catches by each gear. Figure 11 shows the historical catches by various gears. The trap fishery used to be the most important fishery on large bluefin (over 6 years old), while the catches by purse seine and baitboat which concentrate on juveniles (age 2-4) have been increasing significantly in recent years. At the same time, as the price has increased for bluefin tuna in the *sashimi* market, many longliners have been attracted to operate on this stock in recent years and these catches have also been increasing. Therefore, the pattern of interactions among the fisheries must have undergone significant change.

Several bluefin fisheries have disappeared in recent years, namely Norwegian purse seine fishery and Canadian trap fishery. The latter sometimes show signs of recovery from time to time. They are both large-fish fisheries operating at the marginal area of distribution. Therefore, their decline may be an indication of a depletion of stock size or merely of changes in the environment.

In the western Atlantic, there have been many regulatory measures taken since the early 1980s, including strict catch quotas and various size regulations. Those regulations have definitely affected the type of interactions among various gears. At present the purse seine

catches of small bluefin tuna, which used to be the biggest portion of the total catches, have practically disappeared.

3.2 Yellowfin Tuna

Asian longliners used to target yellowfin tuna in equatorial waters, in the 1960s and early 1970s. At that time, the surface fisheries (baitboat and purse seine) were developing very quickly in the eastern tropical waters. In consequence, baitboats and purse seine gears were exploiting yellowfin tuna in the same area, while longline effort was very widespread.

In recent years, most of the longliners no longer target yellowfin tuna but are deploying deep longline gears to catch bigeye tuna. Therefore, the current longline fishing grounds do not coincide as much with the surface fishing grounds for yellowfin, although the surface grounds have extended much further west, which were historically the longliners' yellowfin fishing grounds.

3.3 Albacore

In the Bay of Biscay, traditional fisheries of baitboat and trollers mostly harvesting albacore and some bluefin have been operated out by Spain and France for many years. Since the late 1980s, France developed new albacore fisheries using drift gillnets and pelagic trawls. Since the new fishing methods have been much more effective, most of the French traditional trollers have adopted new gears. However, drift gillnet fishing is illegal for the Spanish fishermen.

This has been causing very serious conflict between the fisheries of the two countries, since both French new fisheries and Spanish traditional fisheries are fishing in the same area and on the same stock, and one is more efficient than the other. While part of the conflict may be due to gear interaction, the major cause is the mere gear competition and the socio-economic problems shared by these countries.

4. INTERACTIONS WITH RESPECT TO SIZE OF FISH

As it is well known, gear interactions can take place in many different ways, such as consecutive and simultaneous interactions.

4.1 Consecutive Gear Interaction

Figures 12, 14 and 16 show size frequencies of Atlantic bluefin, yellowfin and albacore catches, respectively, by surface and longline gears, averaged over a nine-year period. Figures 13, 15 and 17 show catches shared between the surface and longline gears, by size categories of fish. These figures illustrate the location and the size of fish where gear interactions may be taking place.

From these figures, as has been already discussed in the previous sections of this report, it can be concluded that the longline gears catch relatively large tunas while the surface gears catch relatively small tunas. Therefore, if there is an interaction between surface and longline gears, it will occur more consecutively than simultaneously. Surface fishing

reduces the stock size of juveniles and thus, like the longline fishery, affects the adult spawning stocks. For most of the tunas, the spawner vs. recruit relationship is not yet well established and thus the catches by longline may not affect the young tuna populations exploited by the surface gears. However, if such a relation exists, as has been assumed in the bluefin tuna assessments, the possible interactions of these two types of gears are mutual.

However, these same figures also show that in the area where the surface fisheries are developed (North Atlantic for albacore, east Atlantic for yellowfin, and east Atlantic and Mediterranean for bluefin), the absolute number of fish taken by surface gears surpasses the longline catch (Figures 12A and 14A). In many cases, even though surface gears catch relatively small tunas, the actual number of large fish caught by surface gears is greater than that caught by longline. In this sense, both fisheries can be interactive simultaneously as well as consecutively at different life stages of the fish.

Within the surface gears, several gears are exploiting fish stocks at the same stage, area and time, as discussed in the previous sections. Good examples are the purse seine and baitboat fisheries for tropical species (yellowfin, skipjack and bigeye), and the troll vs. drift gillnet and pelagic trawls for albacore in the North Atlantic.

5. MANAGEMENT OF MULTI-SPECIES FISHERIES WHICH HAVE INTERACTIONS AMONG GEARS

The management of tuna stocks which are caught by many gears at different life stages in different waters is very complicated and it is not the objective of this paper to address management issues. However, it should at least be recognized that the management measures aiming to obtain the best biological or economical yield is often not very realistic (see the following paragraphs for real examples). For example, for most tuna stocks, the biological yield per recruit would be increased by increasing the current age of recruitment (or age of first capture) considerably, and increasing fishing mortality of older fish. If the fish price according to the size category is taken into consideration, the economical yield would be increased substantially by restricting the catch to only the very large fish. However, this may result in prohibiting the taking of all small fish, a condition which would penalize usually coastal (often artisanal) fishermen and generally benefit the large industrialized fisheries.

In the case of ICCAT regulatory measures taken for west Atlantic bluefin tuna, the stock of which has been in a very serious condition, the best economical and biological yields have been sought and regulations have been set up to reach those objectives. Besides, in this case only three developed countries (Canada, Japan and USA) are involved in the fishery. However, for the yellowfin tuna and east Atlantic and Mediterranean bluefin tuna, the ICCAT management policy is more flexible, giving consideration to the African and Mediterranean coastal fishermen. The stock condition is, of course, not as serious as that of the west bluefin tuna stock.

Good examples of the above is the minimum size regulations for yellowfin and bigeye (both 3.2 kg), and for bluefin tuna (6.4 kg). This would increase the yield per recruit of these species. However, they are not really implemented. In all these cases, the catch of

undersized fish are well over 50% of the total catches, in terms of number of fish and exceeded to a great extent the legal limit of 15% allowance. It is very difficult to implement the regulations since those small fish are mostly caught by local artisanal fisheries or by developing countries fisheries. Socio-economically those fisheries are very important for these countries.

Nevertheless, management policy should be made with a clear understanding of the fisheries' interactions in order to avoid creating feelings of injustice on the part of the fishermen.

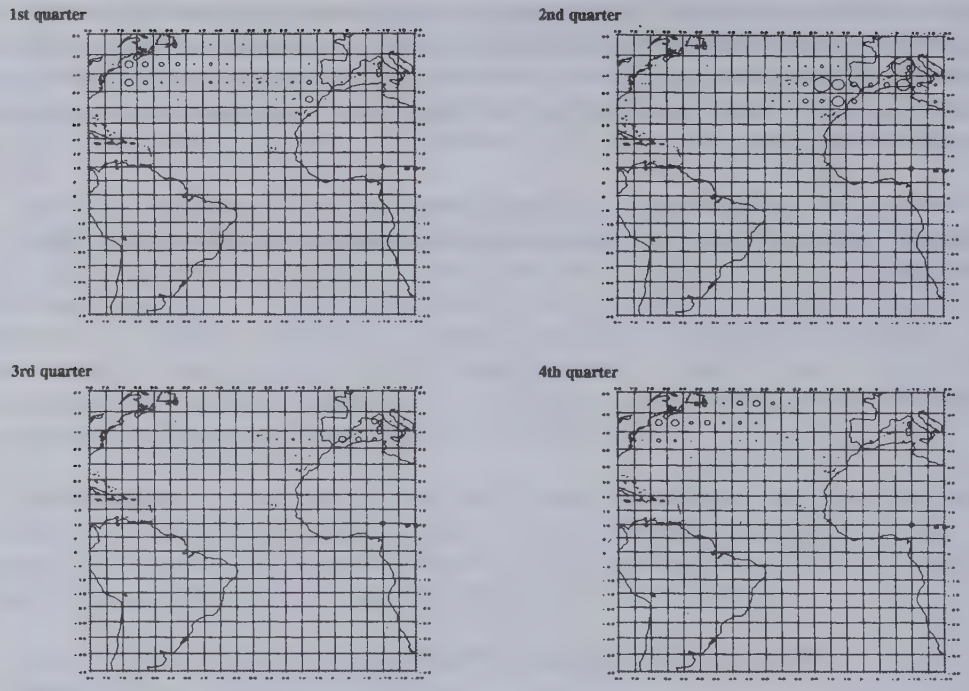


Figure 1. Geographical distribution of bluefin tuna catches by longline fishery, average for 1983-93.

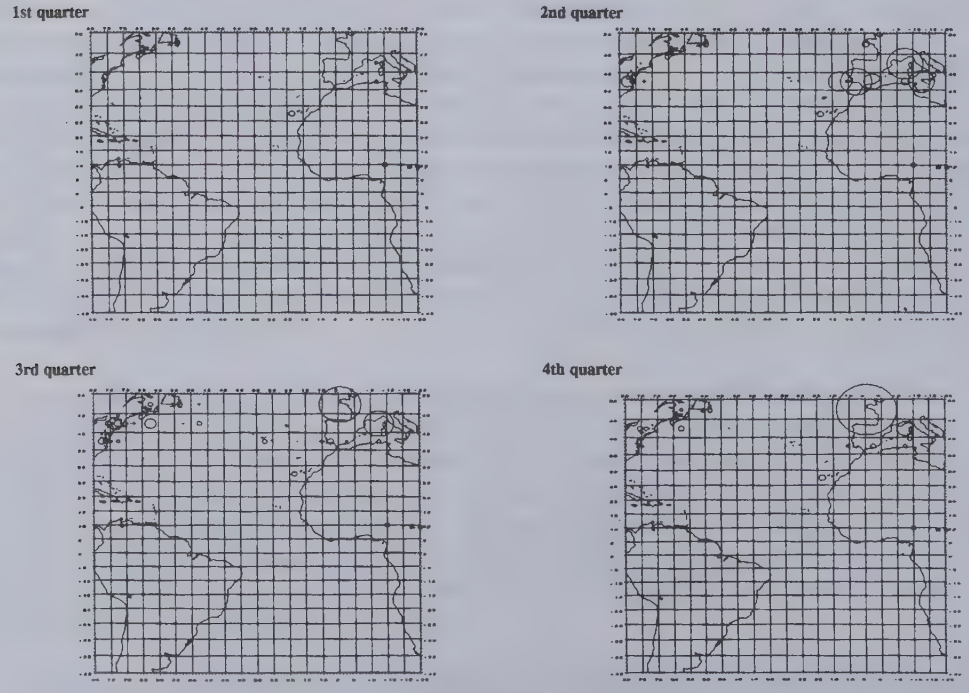


Figure 2. Geographical distribution of bluefin tuna catches by surface fisheries, average for 1983-93.

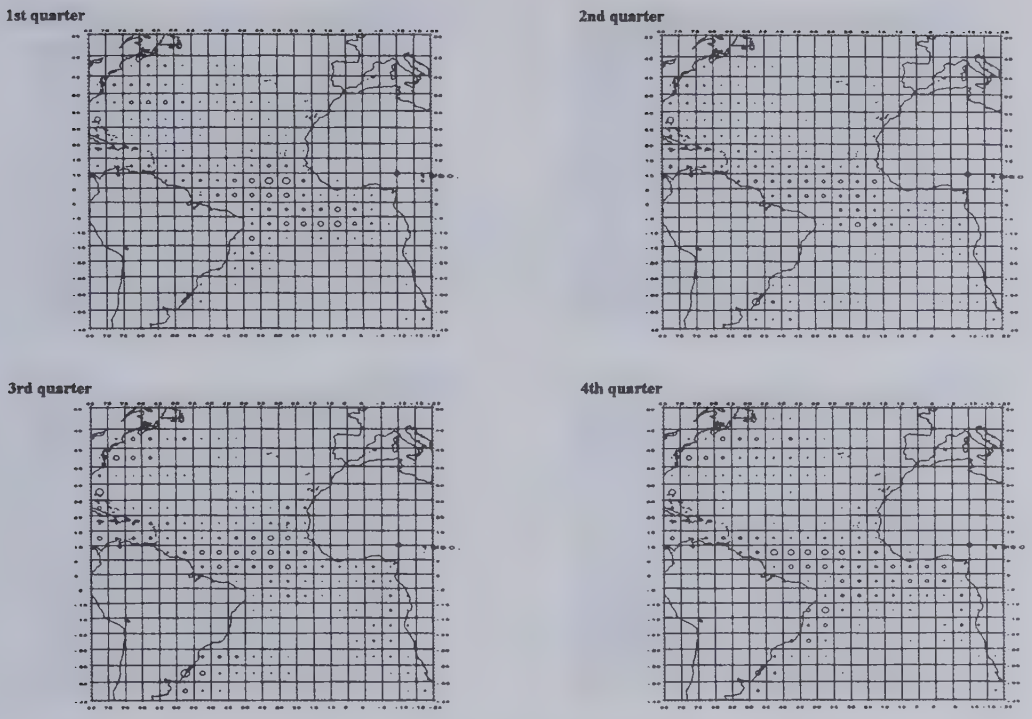


Figure 3. Geographical distribution of yellowfin catches by longline fishery, average for 1983-93.

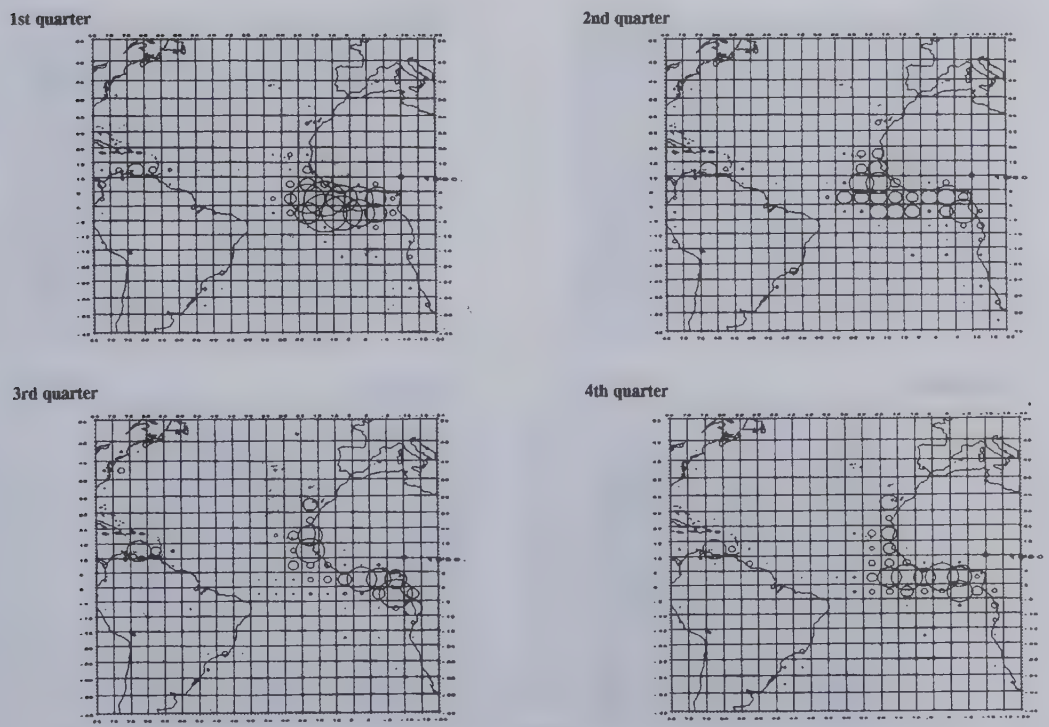


Figure 4. Geographical distribution of yellowfin catches by surface fisheries, average for 1983-93.

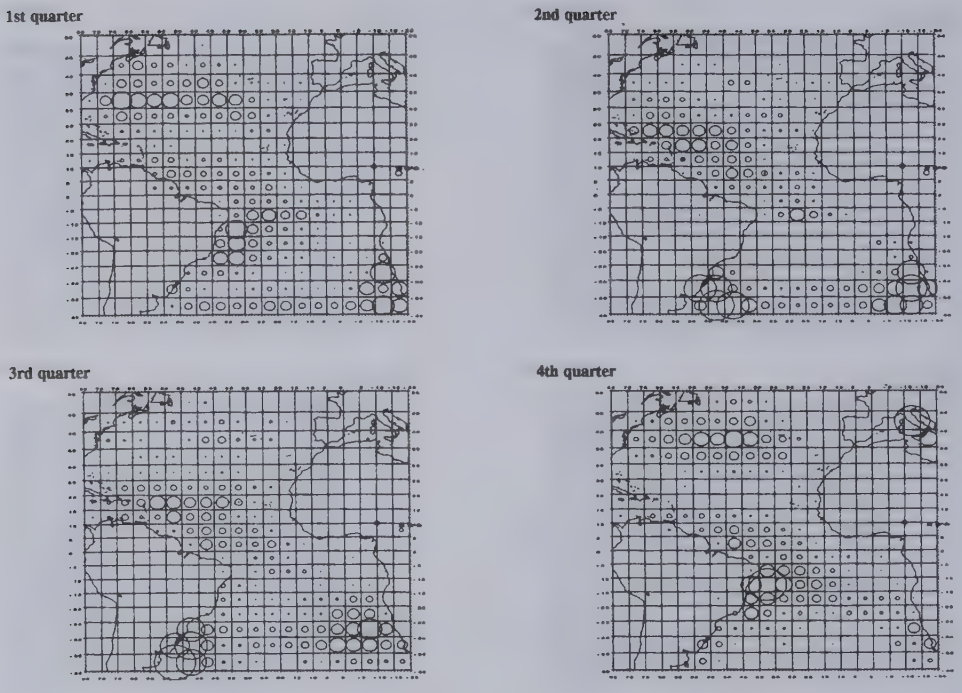


Figure 5. Geographical distribution of albacore catches by longline fishery, average for 1983-93.

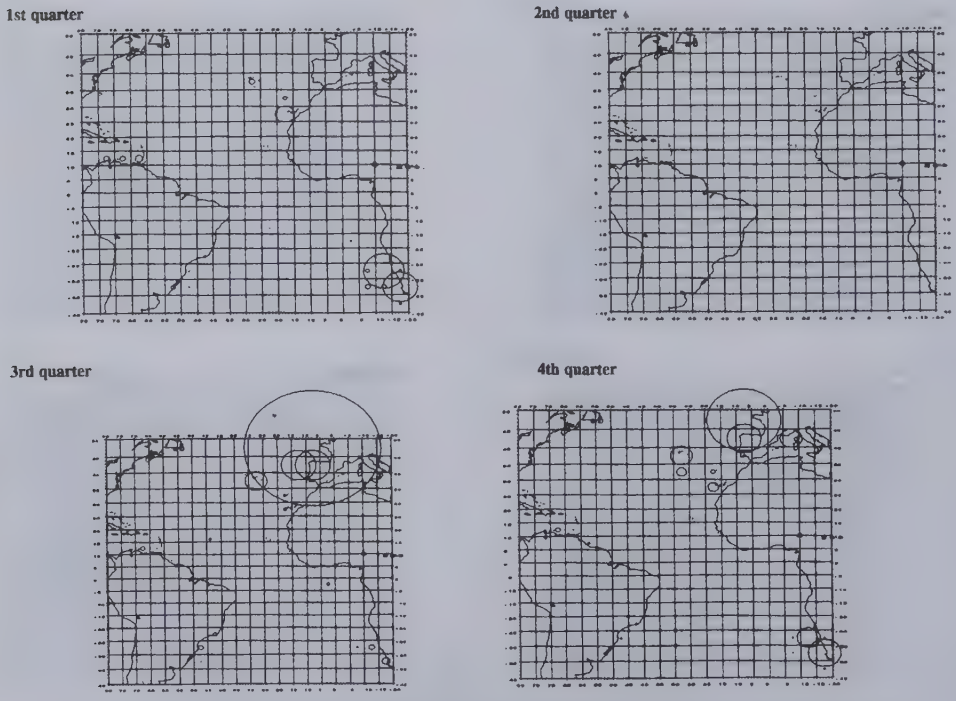


Figure 6. Geographical distribution of albacore catches by surface fisheries, average for 1983-93.

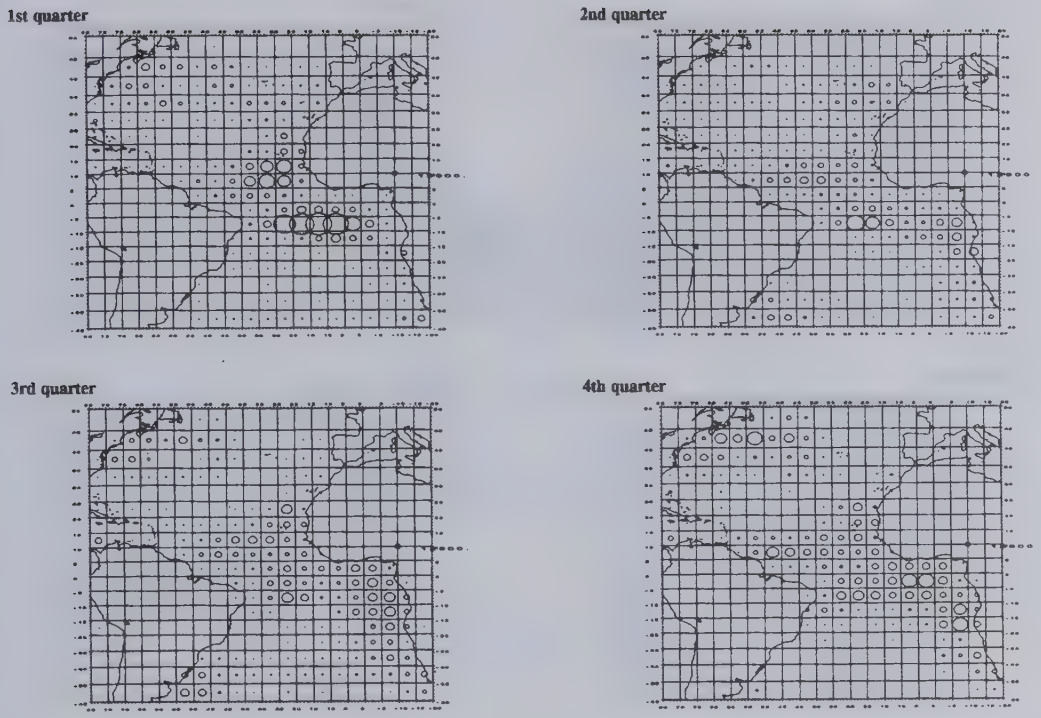


Figure 7. Geographical distribution of bigeye tuna catches by longline fishery, average for 1983-93.

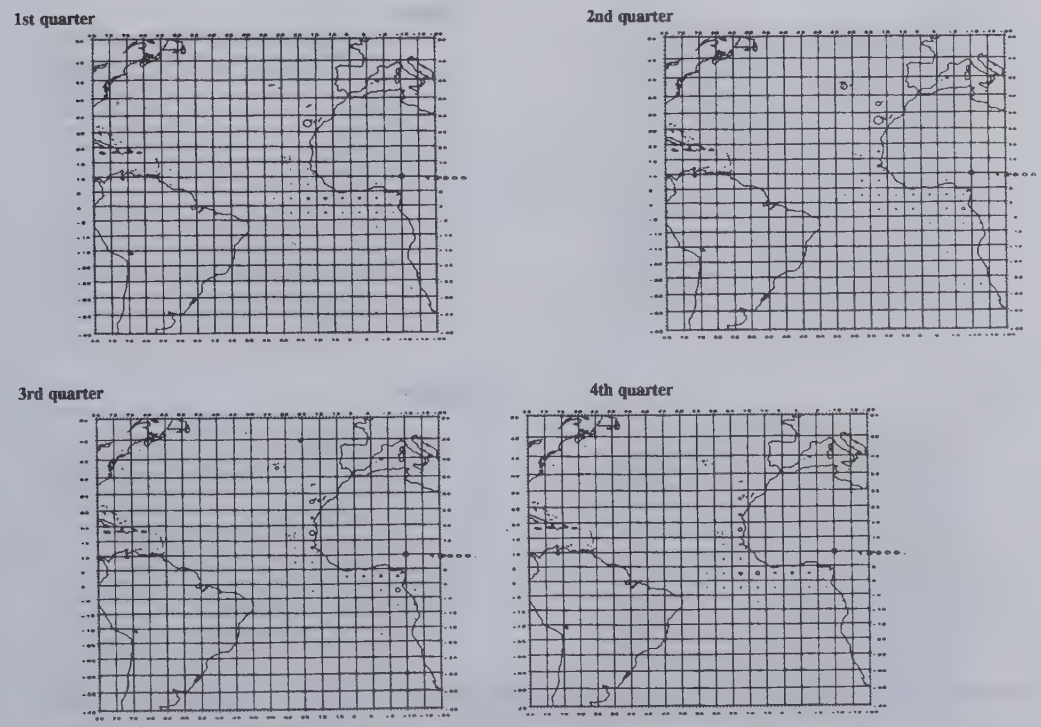


Figure 8. Geographical distribution of bigeye tuna catches by surface fisheries, average for 1983-93.

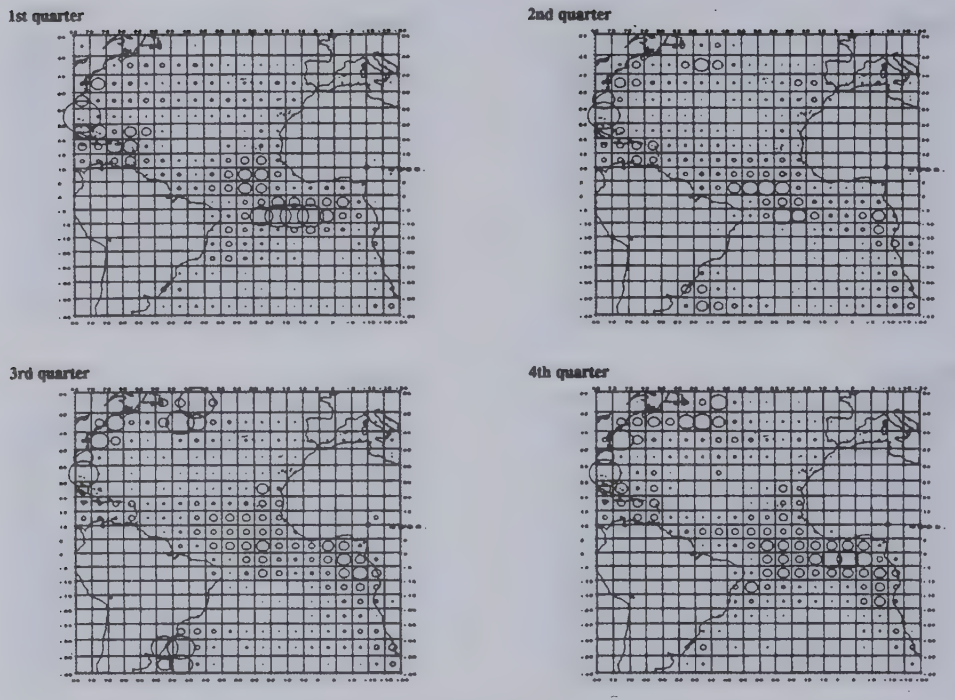


Figure 9. Geographical distribution of swordfish catches by longline fishery, average for 1983-93.

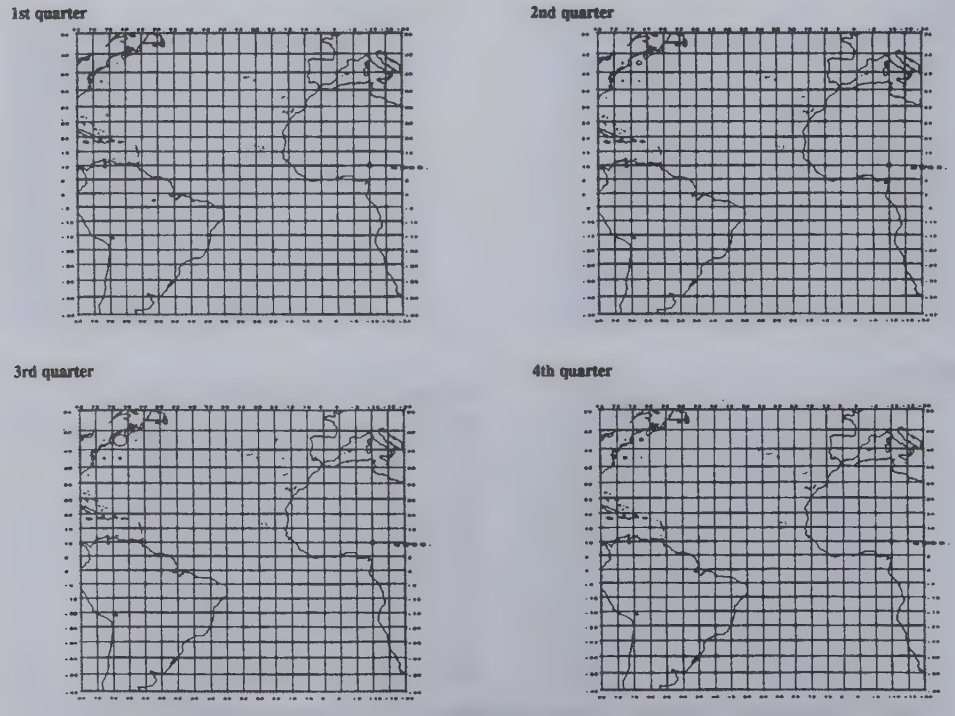


Figure 10. Geographical distribution of swordfish catches by surface fisheries, average for 1983-93.

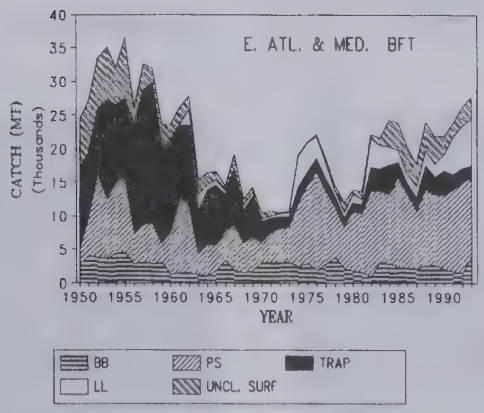
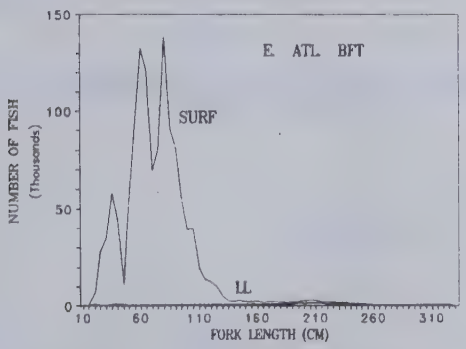
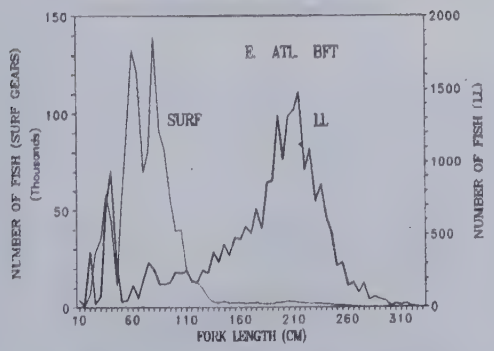


Figure 11. Cumulative bluefin catches (in metric tons) in the east Atlantic (including Mediterranean), by various fishing gears. BB=baitboat, LL=longline, PS=purse seine, UNCL SURF=unclassified surface gear.

A) E. Atlantic (& Med.) bluefin tuna.
Longline and surface plotted on a same scale.



B) E. Atlantic (& Med.) bluefin tuna.
Longline and surface plotted on different scale.



C) W. Atlantic bluefin tuna.
Longline and surface plotted on a same scale.

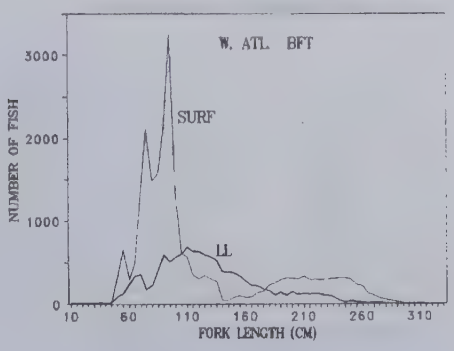


Figure 12. Average size frequecies of bluefin tuna catches for the east and west Atlantic stocks, by surface and longline gears, 1985-93.

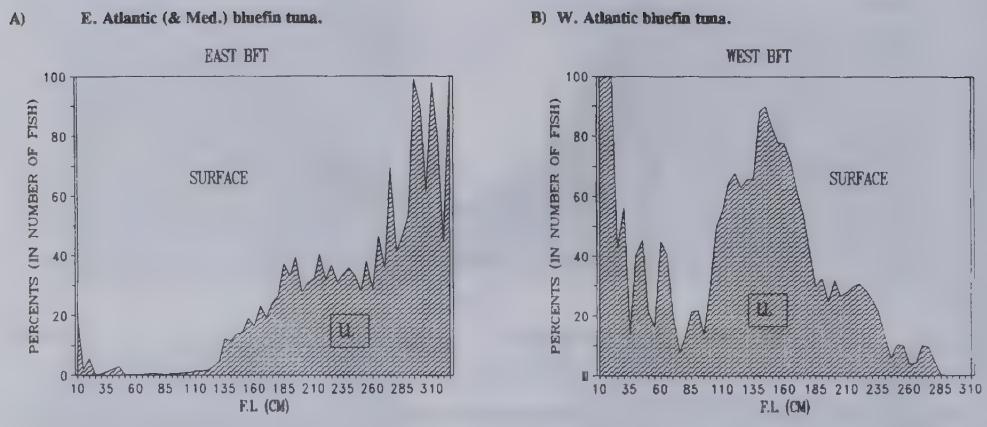


Figure 13. Percentage of longline and surface bluefin catches in each size classe, in the east and west Atlantic, average for 1985-93.

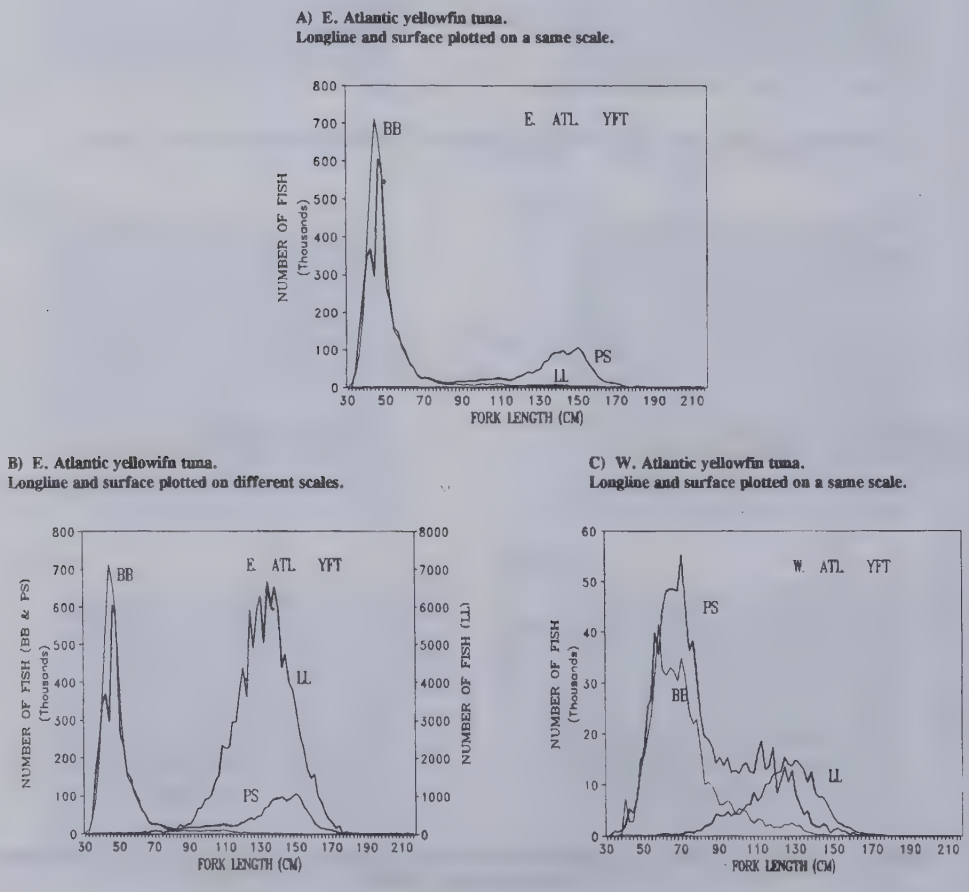

A) E. Atlantic yellowfin tuna.
Longline and surface plotted on a same scale.
E. ATL. YFT
BB
PS
LL
NUMBER OF FISH (Thousands)
FORK LENGTH (CM)
B) E. Atlantic yellowifn tuna.
Longline and surface plotted on different scales.
NUMBER OF FISH (BB & PS) (Thousands)
NUMBER OF FISH (LL)
C) W. Atlantic yellowfin tuna.
Longline and surface plotted on a same scale.
W. ATL. YFT

Figure 14. Average size frequencies of yellowfin tuna catches for the east and west Atlantic stocks, by surface and longline gears, 1985-93.

A) E. Atlantic yellowfin tuna.

B) W. Atlantic yellowfin tuna.

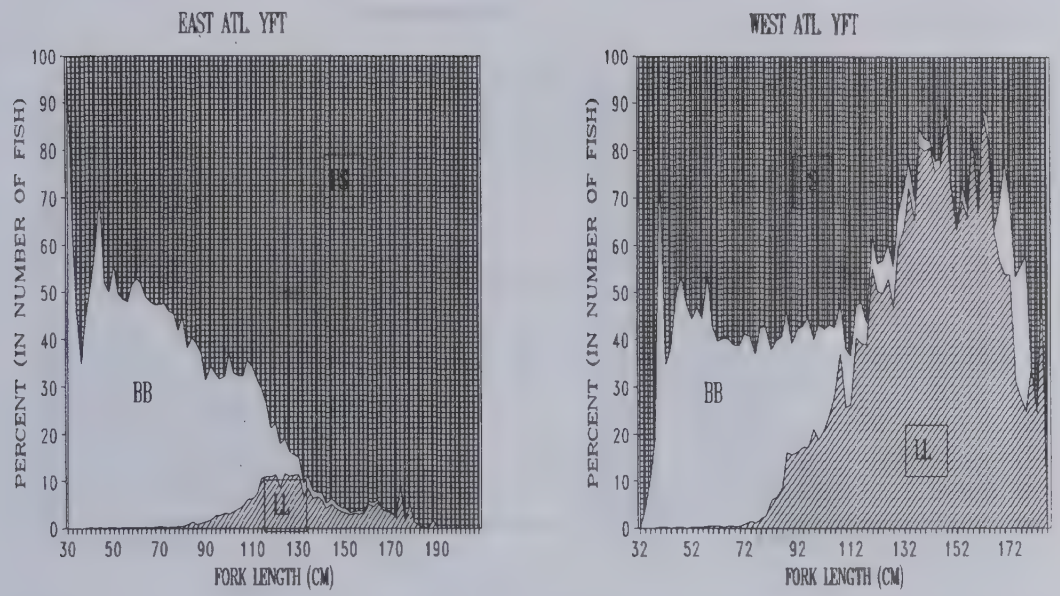


Figure 15. Percentage of longline and surface yellowfin tuna catches in each size classe, in the east and west Atlantic, average for 1985-93.

A) N. Atlantic albacore.

B) S. Atlantic albacore.

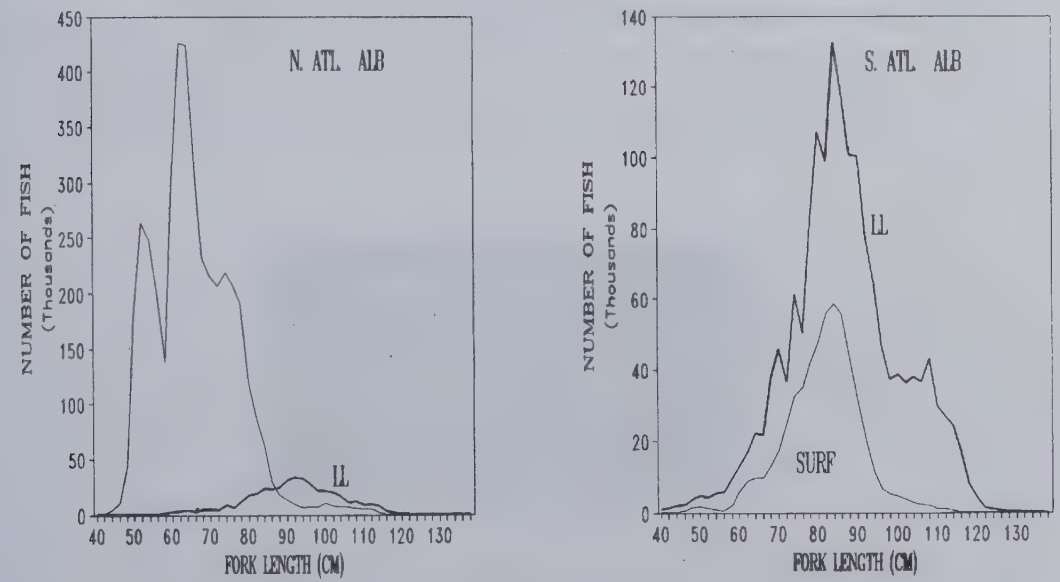
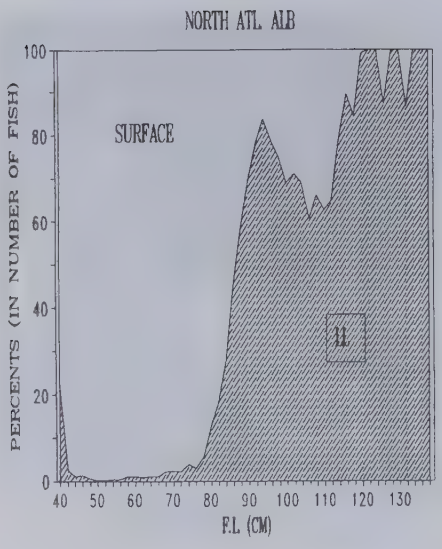


Figure 16. Average size frequencies of albacore catches in the north and south Atlantic, by surface and longline gears, 1985-93.

A) N. Atlantic albacore.



B) S. Atlantic albacore

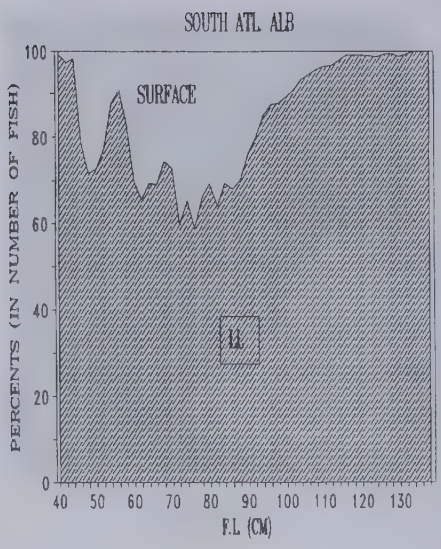


Figure 17. Percentage of longline and surface albacore catches in each size classe, in the north and south Atlantic, average for 1985-93.

SOME INTERACTION ISSUES IN THE FISHERIES FOR TUNAS AND TUNA-LIKE FISHES OF THE INDIAN OCEAN

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ABSTRACT

Increases in the catch of tunas and tuna-like fishes of the Indian Ocean have raised concerns about interactions between major fisheries exploiting those species. After a short presentation of the fisheries and their recent evolution, the paper reviews the main interactions as they currently appear. Each interaction issue is classified according to the type of competition which exists: fisheries catching the fish at the same stage of their life cycle in the same general area, fisheries exploiting fish at two different stages of their life cycle and fisheries exploiting the same stock in two different areas. Past and current work conducted to assess interactions are described and proposals are made for future studies. These include the development of models incorporating movement, the implementation of tagging experiments and increase in the collection of statistical data from coastal fisheries.

1. INTRODUCTION

Tuna fisheries of the Indian Ocean range from subsistence and commercial fisheries (pole-and-line, drift gillnets, purse seining, trolling, handline, etc.) in coastal countries to large industrial fisheries (purse seine and longline) on the high seas and in the Exclusive Economic Zones (EEZs) of several countries. The main particularity of Indian Ocean (compared with other oceans) is the relative importance of coastal fisheries, which have accounted for more than half of the catch of tunas and tuna-like species (Figure 1).

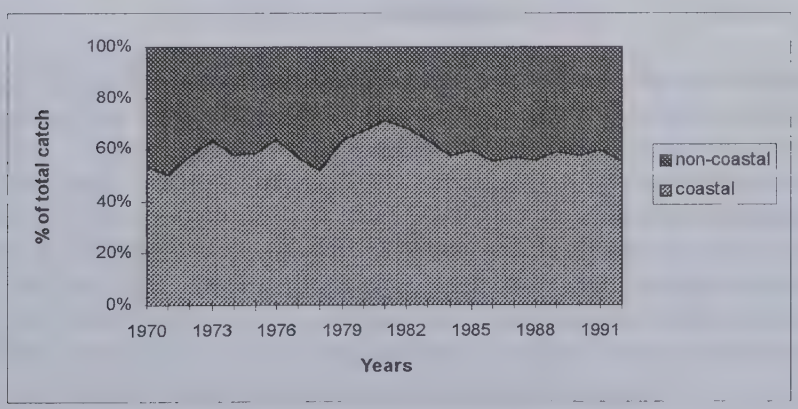

Figure 1. Relative importance of coastal and non-coastal fisheries in the total catch of tuna and tuna-like species in Indian Ocean (FAO Areas 51 and 57) from 1970 to 1992 (source: IPTP, 1994a).

During recent years, trends have been towards an increase in the activity of both artisanal and longline fisheries and the development of a new component, the industrial purse seine fishery, at the beginning of the 1980s. The evolution of both coastal and high-seas fisheries has resulted in a tremendous increase in total catch of tunas and tuna-like species (Figure 2). This growth has been particularly important for yellowfin, whose catches even exceeded those of skipjack in 1992. This difference constitutes another specificity of Indian Ocean compared to other oceans. It has also raised a growing concern about the impact that some fisheries may have on others. Some of those concerns[1] can be summarised as:

- what impact can the distant water fishing nation (DWFN) fisheries (industrial purse seine and longline) have on coastal country fisheries (subsistence and commercial),
- what impact can the development of the purse seine fisheries have on longline fisheries,
- what impact can the DWFN longline fisheries have on locally based longline fisheries, and
- what impact can the development of fisheries for small tunas and seerfish have on the catch of neighbouring countries?

This paper presents some of the major interaction issues that can, with present knowledge, be listed in the Indian Ocean. After a short presentation of the main fisheries and their evolution, it reviews some work already done on interactions, presents some studies currently being carried out and gives recommendations for future work.

2. GENERAL PRESENTATION OF THE FISHERIES FOR TUNAS AND TUNA-LIKE SPECIES

2.1 Evolution and Present Status of the Main Fisheries

2.1.1 Artisanal fisheries

In countries bordering the Indian Ocean, artisanal troll, handline and drift gillnet fisheries have traditionally exploited tunas and tuna-like species, in particular the neritic species such as seerfish, longtail tuna and kawakawa (Figure 2).

In the Maldives, a pole-and-line fishery and, in Pakistan and Sri Lanka, drift gillnets produce significant catches of tropical oceanic tunas. Typically, troll and pole-and-line fisheries exploit all sizes of skipjack and small yellowfin and bigeye tunas. Drift gillnet fisheries in Sri Lanka exploit the same sizes, but, in the Arabian Sea, these gears tend to catch intermediate-sized yellowfin and are the main gears exploiting seerfish and longtail tuna. Handline fisheries exploit large yellowfin, some bigeye and billfish. Artisanal fleets have tended in the past to remain within day-range of their bases. This tendency is changing rapidly, with drift-gillnetters from Pakistan, for example, taking trips of over one-month duration and ranging from the border with India to Yemen and Somalia. In Sri Lanka also, 10-m vessels are ranging off the west coast as far as Maldivian and Lakshwadeep waters.

[1] The albacore drift gillnet fishery, which exploited small fish, may have had an impact on the longline fishery. As driftnetting has now stopped, this effect will disappear within a few years.

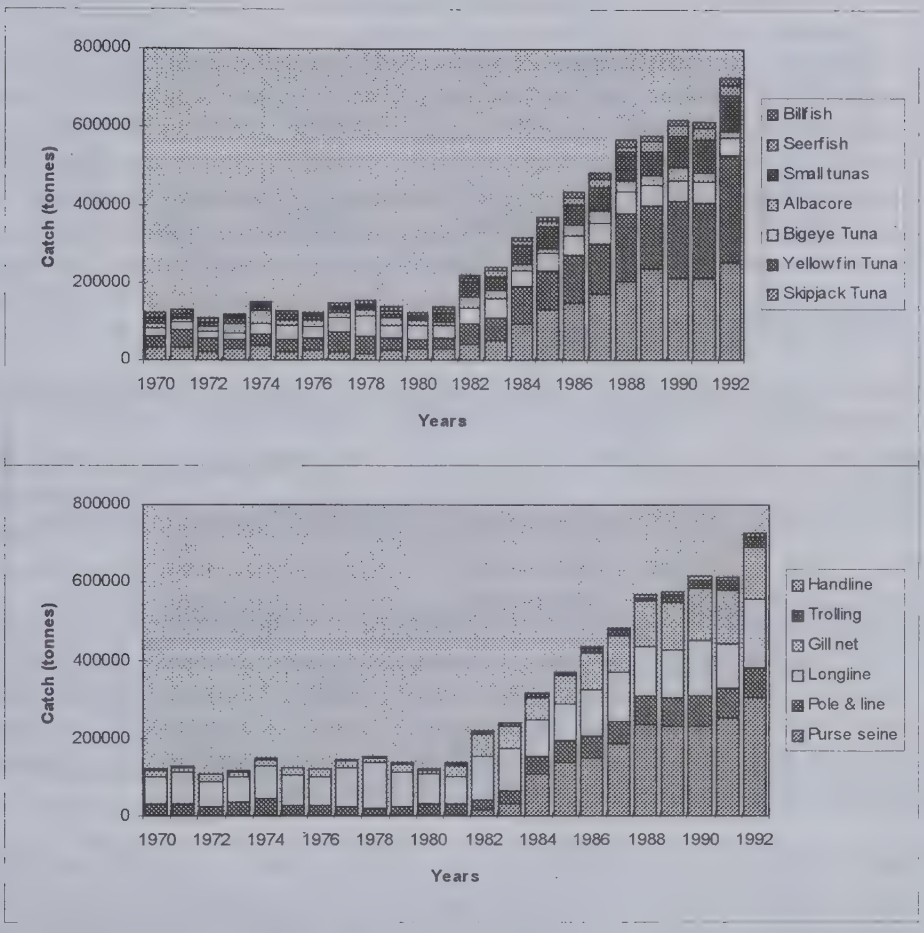

Figure 2. Evolution of tuna and tuna-like catches in Indian Ocean (FAO areas 51 and 57) from 1970 to 1992, by species (a) and gear (b) (source IPTP, 1994a).

Neritic tunas and seerfishes are caught almost exclusively by artisanal fisheries. Longtail tuna, whose distribution is limited to the Indian Ocean and Indo-Pacific, is exploited increasingly by drift gillnet fisheries, particularly in the Arabian Sea and gulfs. The catch of this species was 46,000 mt in 1992 (Table 1); this catch exceeded the Indian Ocean bigeye catch, and is four times the current albacore catch. Seerfish are important throughout the shelf areas surrounding the Indian Ocean basin, and catches peaked at about 110,000 mt, equivalent to the artisanal skipjack catch and one third more than that of yellowfin. This resource is particularly valuable, as seerfish are high-value species in most coastal countries. Important catches of kawakawa are also reported, mainly in countries bordering the Arabian Sea, with more than 50,000 mt caught in 1992 (33,000 mt in India). The other small tunas are of minor importance in the Indian Ocean.

Table 1. Recent catch of small tunas and seerfishes in Indian Ocean.
Source: IPTP (1994a).

Unit: mt

Species	1991	1992
Seerfishes	110,609	105,658
Longtail	42,224	45,953
Kawakawa	51,348	51,707
Frigate and bullet	17,346	17,909
Other tunas (mostly small species)	50,609	50,715

2.1.2 Industrial fisheries

Industrial fishing is more recent in the Indian Ocean. Following trials in the mid-1950s, Japanese longliners entered the Indian Ocean, followed shortly after by the Taiwanese and in 1971 by the Korean fleet. In 1970, the industrial longline fishery was producing close to 100,000 mt, this figure climbing slowly to 150,000 mt in the succeeding twenty years, of which 90,000 mt were yellowfin, 30,000 mt bigeye and 10,000 mt albacore.

The most significant development in this fishery has been the entry into the eastern Indian Ocean and Arabian Sea of hundreds of longliners (mostly under 50 GT), mainly under Taiwanese and, more recently, under Chinese registry. Many of these vessels have re-flagged in coastal countries or are operating under charter or joint-venture arrangements which give them access to EEZs. At this stage, of the coastal countries, only Indonesia has a substantial domestic longline fleet working in the Indian Ocean.

Throughout the range of the longline fishery in tropical waters, yellowfin tuna are the main catch component. North of 10°N, the catch of other tuna species is negligible, but south of this, the main target species becomes bigeye tuna, except for the fishery to the south of Java, where southern bluefin are targeted. There is also a fishery targeting albacore which operates mainly south of the Tropic of Capricorn.

The major part of the production of the longline fleet is for the sashimi market. The large DWFN boats use low temperature freezing, while the coastal vessels conserve most of their catch on ice for air shipment. The albacore fishery produces fish for canning.

An industrial drift gillnet fishery for albacore has had a short life span. This fishery developed in the eastern Indian Ocean in 1985, moving into the western part of the ocean in 1987. The fishery stopped operating in 1992, following the global ban on the use of large-scale drift gillnets on the high-seas. Peak catches, attained in 1990, were 21,142 mt, pushing the total catch of this species beyond estimates of maximum sustainable yield (Hsu and Chang, 1994).

Purse seining started in the Indian Ocean in the early 1980s. The development was very rapid, as a consequence of movement of the French and Spanish fleets from the eastern Atlantic. Catches attained 200,000 mt in 1987 and 310,000 mt in 1992, 157,000 mt being skipjack and 110,000 mt yellowfin tuna. This fishery is conducted mostly by

non-Indian Ocean countries, although a few local vessels operate under joint-venture arrangements.

The main purse seine fleets have two distinct fishery phases. From December to May when the thermocline is well established in the southern part of the Indian Ocean, the fishery targets free swimming schools of large yellowfin. Over the rest of the year, purse seining is conducted mainly on schools of skipjack and small yellowfin, with some juvenile bigeye, aggregated by flotsam or artificial drifting Fish Aggregating Devices (FADs). Between July and August, these fleets are mainly in the more-sheltered waters of the Mozambique Channel, catching mainly skipjack. The Japanese and Mauritian purse seiners fish on FADs throughout the year, and tend to centre on more northern waters. Some fishing is concentrated around seamounts where intermediate-sized yellowfin aggregate.

2.2 Statistical Data Available on Tuna Fisheries in the Indian Ocean

The most complete set of statistical data on tuna and tuna-like species in the Indian Ocean is the Indo-Pacific Tuna Programme (IPTP) nominal catch database. The data are aggregated by year, country, species and gear, and data sets generally go back to 1970. In many countries, however, statistics did not cover tunas adequately prior to the mid-1970s and the 1980s and, until that time, catches were probably greater than records suggest. In a number of cases, species and gear aggregations have been split into their constituent parts using sub-samples. The sub-samples have a limited temporal coverage, and their accuracy is, therefore, suspect.

For most coastal countries, the only information available on the location of catches comes from points of landing. This was adequate when fishing was essentially confined to day-range of the coast, but landings data became increasingly unsatisfactory as fleets range further afield. Equally, effort data are usually limited to fishing-craft statistics. Exceptions are the Maldives pole-and-line and Mauritian purse seine fisheries where detailed effort and length-frequency data are available. Sampling schemes in a number of countries have provided length-frequency data.

For the major industrial DWFN fisheries, catch and effort data are available, usually aggregated by month and 5° grid. For these fisheries, length-frequency data are also available. Non-aggregated data are available to the national institutions which monitor these fisheries, but are generally kept confidential.

2.3 Distribution and Stock Structure of Tunas and Tuna-Like Species in the Indian Ocean

Distribution of tunas and tuna-like species in the Indian Ocean is fairly well established through catch information. The tropical oceanic tunas and billfish range from the Arabian Sea and Bay of Bengal to between 30° and 40°S. Few bigeye, however, are caught north of 10°N. An important fishery for southern bluefin exploits a zone of concentration to the south of Java, but the juvenile migration routes pass around the south of Australia and the species is exploited between 40° and 50°S, from South Africa to Australia and New Zealand. The main longline fisheries for albacore extend slightly to the north of this zone, as far as 10°S in the first and fourth quarters of the year.

Neritic tunas are mainly caught on the shelf areas around the northern half of the Indian Ocean. Seasonal fisheries for both longtail and seerfish operate in the Arabian Sea and gulfs. The catch of seerfish on the east African coast suggests that these fish may undertake coastal migrations.

Very little is known on stock structures and the only study undertaken to date in the Indian Ocean was on yellowfin tuna (Nishida, 1992). This study hypothesised the existence of three stocks, covering the eastern, western and far-western Indian Ocean, with some degree of intermingling in adjacent areas. The study used analysis of variance for CPUE, age-specific CPUE and coefficient of variation for size (CVS) to distinguish among stocks. This approach needs to be confirmed by other methods. Mitochondrial DNA studies on juvenile yellowfin from various parts of the Ocean have not to date been reported on (S. Chow, IPTP, pers. comm.).

3. KINDS OF INTERACTIONS CONSIDERED

In this paper, interactions are restricted to what Kleiber (1994) called resource-mediated interactions. This excludes possible competition in marketing or interference between gears. Furthermore, some aspects of the harvest competition defined by Kleiber as secondary effects will not be considered. These secondary effects concern the exploitation by one fishery of the food of the target species of the other fishery or the effect of heavy exploitation of the spawning stock on recruitment. Those two aspects are, up to now, not thought to be significant in tropical tuna fisheries. The definition is therefore restricted to interactions which occur when a fish which could have been harvested by a fishery has been caught by another. If we follow Hampton (1994), the reasons for interactions can be categorised as:

Type A. Competition for fish at the same stage in their life cycle in the same general area by two or more fisheries.

Type B. The effect of fishing a stock at an early stage in its life cycle upon a fishery that exploits the stock at a later stage, typically with another gear.

Type C. The effect of fishing a stock in one area upon a fishery that exploits the stock elsewhere.

A summary of the main tuna fishery interactions that are of current concern in the Indian Ocean is presented in Table 2. The column labelled "Type" gives the category of interaction according to the above classification. Gears used in subsistence and commercial fisheries in coastal countries (pole-and-line, drift gillnets, purse seining, trolling, handline, etc.) have been aggregated under "small-scale fisheries".

Table 2. Main tuna fishery interaction that are of current concern in the Indian Ocean.

Description	Species	Affecting Fishery Area/Countries involved	Gear	Affected Fishery Area/Countries involved	Gear	Type
Interaction between DWFN purse seine fishery and longline fisheries (DWFN and locally based)	yellowfin bigeye	WIO (Seychelles, Mozambique Channel, Chagos, moving to north Arabian sea) France, Japan, Spain, USSR	purse seine	All Indian Ocean Taiwan, Japan, Korea Indonesia, Mauritius, India, Oman, Pakistan, Sri Lanka, Yemen, Maldives	longline	mainly B or C, (some A)
Interaction between DWFN purse seine fishery and small scale fisheries	skipjack yellowfin bigeye (?)	WIO (Seychelles, Mozambique Channel, Chagos, moving to north Arabian sea) France, Japan, Spain, USSR	purse seine	Maldives Iran, India, Oman, Pakistan, Sri Lanka Comoros, India, Indonesia, Sri Lanka, Pakistan	pole-and-line drift gillnet handline trolling	C B A, B or C
Interaction between DWFN longline fishery and locally based longline fishery	yellowfin bigeye	All Indian Ocean Taiwan, Japan, Korea	longline	Indonesia, Mauritius, India, Oman, Pakistan, Sri Lanka, Yemen	longline	A or C
Interaction between fisheries for small tunas	seerfish longtail kawakawa	Arabian Sea Yemen, Oman, UAE, Iran, Pakistan, India, Sri Lanka	drift gillnet trolling hand-line	Arabian Sea Yemen, Oman, UAE, Iran, Pakistan, India, Sri Lanka	drift gillnet trolling handline	A or C

4. REVIEW OF MAIN INTERACTIONS IN THE INDIAN OCEAN

4.1 Interactions Between Purse Seine and Longline Fisheries

4.1.1 Description of the potential interactions

The longline fisheries exploit virtually the whole of the Indian Ocean, whereas the purse seine fishery has developed only in the western and central part. Potential interactions are of the three types, as the purse seine fishery exploits both juvenile yellowfin and bigeye associated with flotsam and large yellowfin in free-swimming schools. It must be noted that another possible type B interaction may exist here between purse seine fisheries catching different sizes of yellowfin. This however depends on how we define the term fishery, as many purse seiners are involved in both fishing techniques.

Yellowfin is probably the more affected species, as purse seine catches of bigeye amount to only about 8% of yellowfin catches. The increasing tendency to exploit flotsam and FAD-associated schools with deep nets, however, will add to fishing pressure on bigeye. Bigeye are commonly found at depths below the yellowfin and skipjack aggregations. This trend is confirmed by the recent increase in the purse seine catches of bigeye which accounted for half of the catch in weight of this species in 1991. As purse seiners are catching mainly small sizes of bigeye, this could represent a large number of fish and raise concern of type B interaction between purse seines and longlines.

4.1.2 Assessment of interactions

Analysis of catch and effort data, using a General Linear Model (GLM) has not been conclusive. Despite the sharp increase in the yellowfin catch of the purse seine fishery in the early 1980s (from 20,000 mt in 1983 to more than 100,000 mt in 1989), the CPUE of longliners has not appeared to be affected (Figure 3).

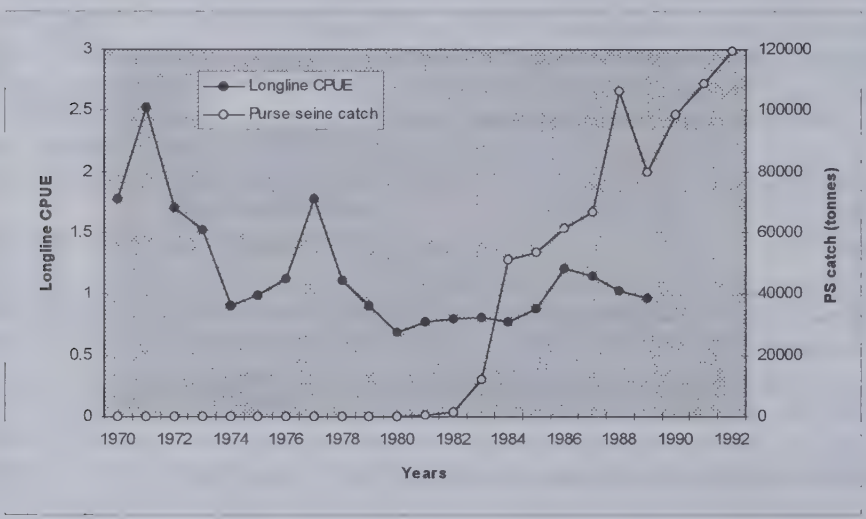

Figure 3. Trends in the longline CPUE and purse seine catch from 1970 to 1992. Longline CPUE have been standardised from Japanese, Taiwanese and Korean CPUE using GLM method. Source: IPTP, 1994b.

On the other hand, simulations conducted using fishing mortality by gear obtained after the use of catch-at-age data and sequential population analysis, but with no spatial pattern introduced in the model (IPTP, 1991, and Bertignac, 1994a), showed that interaction between purse seines and longlines should occur if the two fisheries are exploiting the same stock. Several hypotheses can explain this discrepancy:

i) the stocks available to the two fisheries are not (at least partially) the same,
ii) the stock is huge, or
iii) the measure of fishing effort is biased.

Concerning the first hypothesis, a way of getting complementary information (e.g., movement rates between fisheries, possibility of exchange between surface and sub-surface stocks) would be to conduct tagging experiments. Proposals were made at the last workshop on Indian Ocean Yellowfin stocks (IPTP, 1991) and reiterated at the last Expert Consultation on Indian Ocean Tunas (IPTP, 1994b) for the implementation of such a programme. Where tagging has been conducted in the past, recoveries in the longline fishery of fish tagged in surface fisheries have been less than expected. However, as mentioned by Hampton (1994), several explanations can be given to such discrepancy (lower reporting rates in the longline fishery, only partial recruitment to the longline

fishery of the population of which the tagged fish are representative, existence of two different population implying that fish available to the longline fishery have never been available to the purse seine fishery) and "conventional" tagging does not provide enough information to discriminate between the fisheries. Tagging large yellowfin in both the surface and longline fisheries would help to answer questions on the availability of fish to both fisheries. Technically, such a tagging is possible as the South Pacific Commission Regional Tuna Tagging Project has tagged large yellowfin at the surface using short handlines. Some large line-caught bigeye and billfish have also been tagged successfully (Boggs, 1992). The use of sonic and archival tags might also help to establish behavioural differences which could explain varying vulnerability to surface and deep-water gears.

In regard to point ii), exploitation rates that can be obtained by tagging experiments (as described above) would also be useful. If we simply look at the FAO catch statistics, we can see however that compared to the yellowfin production of the western Pacific in 1992 (~400,000 mt), the Indian Ocean which is of equivalent size to the western Pacific has produced around 220,000 mt during the same period. Assuming an equivalent productivity (which might be a little bit simplistic), this would suggest that the Indian Ocean is capable of supporting larger catches of yellowfin.

To address point iii), it is obviously necessary to improve the standardisation of the longline CPUE data. This could be done by using a model incorporating biological and oceanographic data such as the one currently developed on Pacific billfishes (Bayliff, 1994, page 5).

For bigeye, very few studies have been conducted to date. Analyses have been made using a surplus production model which did not incorporate the purse seine fishery (Hsu and Chang, 1994). No interaction analysis has been carried out. As with yellowfin, the development of an age-structured model would be recommended if the objective is to study interactions (purse seine vs. longline). We saw above that seiners are catching large numbers of young bigeye. However, availability of data is much lower than for yellowfin and we know little of the biology (e.g., growth, movement). Furthermore, the quantity of bigeye caught by coastal fisheries is still unknown and is probably underestimated, due to the difficulty of distinguishing small bigeye from yellowfin.

4.1.3 Data requirements

IPTP holds catch and effort and length-frequency data for both purse seine and longline fisheries. These data would be satisfactory for age-structured models. Tagging is expected to improve our knowledge of growth for yellowfin (and maybe bigeye) as well as give some insight on movement needed for models incorporating a spatial component.

4.2 Interactions Between Purse Seine and Small-Scale Fisheries

4.2.1 Description of the potential interactions

In the Maldives, an important fishery using pole-and-line as the main gear is presently catching more than 60,000 mt of skipjack and 10,000 mt of yellowfin. This fishery is of prime importance for the country, and concerns exist about the increases in the catch of

purse seiners. FADs deployed by purse seiners on the high seas have drifted ashore on the islands under the effect of the Equatorial Countercurrent. This has caused concern among small-scale fishermen in the Maldives that schools contributing to the influx of tunas could be caught prior to their arrival in coastal waters. Sri Lanka is also dependent on skipjack and small yellowfin for its drift gillnet fishery and could be similarly affected. The problem could be compounded by the fact that the purse seine fishery is moving further north and east year by year. The interactions here would be of types A or C.

Other locally-based commercial fisheries which could be affected, at long range, by the development of the purse seine fishery are the drift gillnet fisheries of the northern part of the Arabian Sea. The target species is yellowfin of an intermediate size, so that type B interactions are possible.

Similar type A, B or C interactions may occur between purse seine fisheries with countries using traditional gears such as troll lines (type A or C) and handlines (type B). While the effect on total catches might be minor, the negative effect on the livelihood of fishers could be significant.

4.2.2 Assessment of interactions

Few studies have been conducted to assess the effect of the purse seine fishery on the pole-and-line and drift gillnet fisheries. The simulations on the yellowfin fisheries mentioned above (4.1.2) indicated a low level of interaction, although no spatial pattern was introduced in the model. To get information on the migration patterns and status of stocks in the Maldives, a tagging experiment was conducted in 1990. Of the 8,033 skipjack and 1,908 yellowfin tagged, 1,407 and 128 have been recovered, respectively. This tagging experiment has given information on movement of fish inside and outside the area, and estimates of natural and fishing mortality (Yesaki and Waheed, 1992; Bertignac et al., 1994; Bertignac, 1994b). The diffusion rate of skipjack inside the Maldives was found to be low compared with other regions (e.g., the western Pacific), which seems to indicate that some sort of a local population exists in the Maldives. At the same time, exploitation rates obtained were moderate, indicating a low level of fishing mortality compared with natural mortality and emigration from the area.

To date, no estimate has been made of the recruitment to the fishery, as fish were tagged only in the Maldives, but there is no reason to believe that recruitment has not been sufficient to compensate the losses due to fishing, natural mortality and emigration. This should reduce concerns about the status of the Maldivian skipjack fishery.

Some tag recoveries were made outside the Maldives, showing that at least some skipjack and yellowfin migrate from Maldives to Sri Lanka and the western Indian Ocean, where other important fisheries exist. Those recoveries were, however, not sufficient to quantify movement rates outside the Maldives. A second tagging programme is currently being carried out. Its objectives are to put more emphasis on yellowfin and offshore skipjack tagging. Some tetracycline injection is being conducted for growth studies, as well as double tagging to more accurately estimate tag-shedding parameters.

As mentioned above, there is not much concern about the skipjack stock to date. This may not be the case for yellowfin where, although no signs of interaction are visible, the stock has a higher probability for over-exploitation. Where we are dealing with type C interactions, rates of movement of fish between fisheries and local recruitment are the key elements. The regional tagging project mentioned above could address those aspects. Tagging results would be then used in simulation models incorporating movement between fisheries, permitting the estimation of interaction. This type of model requires good-quality data.

4.2.3 Data requirements

Accurate and complete data are available on the industrial purse seine fisheries. For coastal fisheries, catch and effort data are of relatively good quality in the Maldives, but this may be not the case for other coastal fisheries, e.g., those bordering the Arabian Sea. Some improvements are thus required in the collection and compilation of statistics from those countries. The approach recommended by IPTP is to establish sampling schemes for representative fisheries in the countries concerned, using the data to split aggregated figures available from national statistical systems. The IPTP has assisted by designing sampling schemes, developing software for data entry and analysis and training staff in Sri Lanka, Pakistan and Iran and has, in certain cases, provided equipment and funded staff for limited periods.

4.3 Interactions Between Longline Fisheries

4.3.1 Description of the potential interactions

Interactions can include type A (local) but are more likely to be of type C (spatial), as most of the DWFN longline effort is in high-seas areas. Yellowfin and bigeye are the main species involved in this interaction issue. Large fishes are targeted. Both DWFN and coastal longline fisheries are of importance for the region, as they are a source of income and social benefits for many countries through license agreements, chartering, and induced activities of landings.

4.3.2 Assessment of interactions

No assessments have been conducted on this interaction issue. Although data are still not available, reports indicate a drop in the longline CPUE in the Arabian Sea in 1993 (G. Carrara, pers. comm.). This may be due to a number of factors, including recruitment and vulnerability of the fish to this gear, but could also be an indication of type A or C interactions between longline fisheries. If the growth of the fishery was to continue at the present rate, some acute type A interactions could emerge. Future studies should concentrate on yellowfin and bigeye, which are the main species caught. In the case of type C interactions, the main problem will concern the rates of movement of large yellowfin and bigeye, which are unknown. Here also, tagging with fish released in both fisheries will give some information useful for the development of spatial models.

4.3.3 Data requirements

The IPTP has not to date obtained catch and effort or length-frequency data from coastal longline operations, except for an extensive length-frequency data set covering one year for landings at Penang. Contacts are being established with authorities in India, Pakistan, Iran, Oman and possibly Yemen for establishing logbook, observer or shore-sampler programmes to obtain the desired data. Observers may be able to obtain data on discards, which are important in longline fisheries producing tuna for the sashimi market.

4.4 Interactions Between Fisheries for Small Tunas and Seerfishes

4.4.1 Description of the potential interactions

The recent drop in the catches of seerfish and longtail tuna in Oman (Figure 4) has raised concerns about the status of these resources and possible interaction between fisheries in the region.

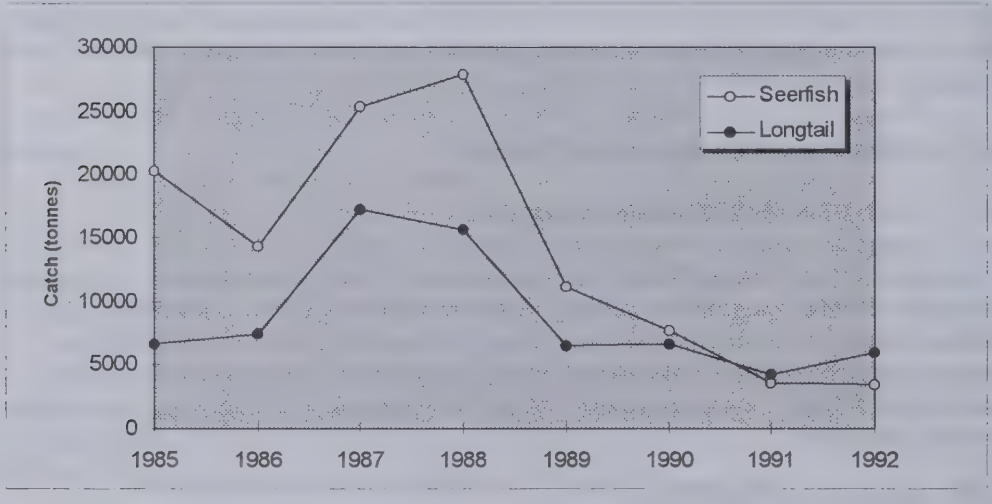

Figure 4. Seerfish and longtail tuna catches in Oman.

The main gears used are drift gillnets, with some catch made by handline or trolling. Little is known of the stock structure and age distribution of the catch. It is thus difficult to say which type of interaction we are dealing with. We can however assume that it is mainly a type C interaction with some type A interaction. Unknown quantities of small seerfish are also caught by trawlers, particularly in India. In that case, a type B interaction might exist.

4.4.2 Assessment of interactions

A preliminary assessment of interaction in a fishery for small tunas has been conducted in the Gulf of Thailand. Simulation studies were carried out using a length-based model

aggregated in space (Bertignac and Morón, 1994). The study underlined the impact that a fishery harvesting large quantity of juveniles of small tunas (mainly kawakawa) can have on other fisheries targeting larger fish (type B interactions). It shows, however, the limitations of this type of model when the whole distribution of the stock is not covered by the analysis.

No assessments have yet been undertaken of interaction between fisheries for small tunas and seerfishes in Indian Ocean *sensu stricto*. Following recommendations made at the last Expert Consultation on Indian Ocean tunas in Mahé, Seychelles, 1993, a project to assess seerfish and longtail tuna fisheries in the Arabian Sea and gulfs has been made by IPTP. The preliminary intention is to use multi-gear yield-per-recruit models aggregated in space. Such a simulation model, with only one gear (drift gillnet), was used to analyse the seerfish fishery in Oman and has been promising (Dudley et al., 1992; Bertignac and Yesaki, 1994). The inclusion of gear components in this model would help to assess whether type B interaction can potentially be important (see above the remarks on seerfish catches by trawlers). If type C interactions also prove to be important, the inclusion of spatial dimensions will be necessary and involve the estimation of movement rates between fisheries. Tagging of longtail does not appear to be an insurmountable problem, but to our knowledge, no tagging of seerfish has been conducted to date.

4.4.3 Data requirements

In the project mentioned above, proposals are made for the collection of data on catch and effort in each country involved in the fishery and on length-frequency distribution of the catch. Compilation of all information available on the fisheries and collection of biological data are also requested.

5. CONCLUSIONS

This paper represents an attempt to review the main fishery interaction issues in the Indian Ocean as they appear with the present knowledge we have of the fisheries for tuna and tuna-like species. Several potential interactions currently considered as minor have not been mentioned. These include, for example, the potential impact of longliners on local sport fisheries for billfish. Even if they are not of prime importance for Indian Ocean as a whole, such interactions can be important locally, and should not be ignored. As stated above, interactions which may have occurred between drift gillnet and longline fisheries for albacore have not been examined as, with the ban which has taken effect on drift gillnet fishing, no further research or management is justified. Similarly, interactions in southern bluefin fisheries are not examined as they are being tackled by the newly established Convention for the Conservation of Southern Bluefin Tuna.

Whatever types of interaction we have to address, having reliable statistics is an important element. Up to now, we can assume that there has not been a major problem with industrial fisheries (purse seiners and longliners) where, generally speaking, data are of good quality (catch and effort statistics and length-frequency distributions) and are sent to IPTP with acceptable delays (IPTP has recently faced problems to get catch and effort and length-frequency distribution from Korean longliners and Japanese data are submitted

with considerable delay. The latter problem is expected to disappear with the development by Japan of a real-time catch reporting system).

On the other hand, data from the recently-developed coastal longline operations have not yet reported their catches to IPTP. A sampling programme was implemented in Malaysia, but was not maintained at the termination of IPTP support. Contacts have also been established with local authorities (in India, Pakistan, Iran, Oman and Yemen) to establish logbook or observer data collection systems. This is expected to produce information in the future on catch and effort and length distribution of catches. Observers could also obtain information on discards which are known to be important in the longline fisheries producing tuna for the sashimi market.

Another major problem concerning statistics is the availability of data from coastal fisheries. Although the Maldives are reporting good quality catch and effort statistics, statistical systems in bordering countries are often producing aggregated data. These data are difficult to use in any assessment studies. Furthermore, few length-frequency distributions of the catch have been collected to date. In some countries, statistics produced now are even of poorer quality than in the past. However, it seems hard in the present situation to improve significantly on that aspect due to the characteristics of all artisanal fisheries (small quantities landed in a large number of landing sites), the cost of the sampling (money and time) and the difficulty of monitoring enumerators. Tuna and tuna-like species may also not support priority fisheries in many of the countries concerned, justifying the necessary detailed statistical treatment. The IPTP has tried to mitigate the lack of data by implementing sampling programmes (Malaysia, Sri Lanka, Pakistan, Iran and Indonesia), but these are limited in space and time.

In addition to the quality of data, the type of data to collect is an important issue. We have seen that, for yellowfin and bigeye, potential interaction issues were mainly a combination of type B and type C (with some type A in areas where both purse seiners and longliners operate). In such cases, assessment of interactions could involve the use of simulation models incorporating both movements and size/age distribution of the catch. Such model should allow the estimate of the effect of variations in the activity of one fishery on the performance of the others under various conditions. Some progress is still to be made in the study of the growth of yellowfin and bigeye and the collection of length-frequency distributions for bigeye. No information is available on movement of either species. The large-scale tagging programme proposed for the Western Indian Ocean should provide such information and should try to investigate questions related to growth of yellowfin or/and its availability to surface and longline gears. Bigeye will presumably be tagged on an opportunistic basis, but it may be difficult to capture sufficient juvenile fish to study interactions in the small sizes. Tag recoveries could be analysed using tag attrition models incorporating movements (Sibert and Fournier, 1994). The objectives and implementation of the tagging programme are still to be finalised. Some simulations are currently being conducted by IPTP to investigate different patterns in the tagging process. In parallel to these tagging experiments, IPTP should try to improve data collected from drift gillnet fisheries in the Arabian Sea (catch and effort and length frequency distribution).

The main interaction issue for the stock of skipjack is a type C interaction between the purse seiners in the western Indian Ocean and the pole-and-line fishery in the Maldives. Tagging conducted in the latter fishery has shown that, locally, the fishing pressure is still low. For a complete picture of the stock dynamics, however, estimation of movement rates between the fisheries, population size and fishing and natural mortality could be made, using spatial models (Sibert and Fournier, 1994). Estimates of local recruitment are also important. As this is not a type B interaction, the size or age of the fish caught is not a major issue in a preliminary approach. All this would imply the implementation of a large scale tagging programme similar to the South Pacific Commission Regional Tuna Tagging Project. As the Indian Ocean skipjack stock is probably less heavily exploited than those of yellowfin and bigeye (as it is the case in other oceans), such a tagging programme, thus, may not be a priority in the medium term.

The project proposed by IPTP for the creation of a working group on seerfish and longtail tuna fishery in the Arabian Sea should permit the conduct of preliminary assessments of those stocks. Emphasis will be put on seerfish, which is economically more important for the region and for which the use of methods separating modal size groups, e.g., the Bhattacharya method described in Bhattacharya (1967) or Multifan (Fournier et al., 1990) seem to be particularly appropriate. Assessing the impact each gear/country might have on the others will necessitate the collection of catch and effort data and length-frequency distributions by fishery component. A spatial dimension could also be incorporated into the model. Tagging experiments may provide some insight into these matters.

Although statistical analyses of fishery data (CPUE and catches) have not yet been conclusive and are in any case difficult to interpret from an interaction point of view, they still need to be investigated further. If GLM techniques are to be used, very precise catch and effort data are needed (possibly on a daily basis), together with operational data, boat and gear characteristics, environmental data associated with the catch, etc. to permit the separation of major factors playing a role in catch rates. Although the present data compiled by IPTP covers the needs partially, some progress is still to be made, depending on the species considered.

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INTERACTIONS BETWEEN TUNA FISHERIES: A GLOBAL REVIEW WITH SPECIFIC EXAMPLES FROM THE ATLANTIC OCEAN

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ABSTRACT

This paper has two goals. The first is to develop some general considerations about the issue of interactions between tuna fisheries; the second is to review interaction problems in the Atlantic Ocean. The general consideration include a discussion of the types of tuna migrations, since migration is a key component in the interaction phenomenon. The potential importance of a "cryptic biomass", i.e., a fraction of the tuna stock with low catchability, is stressed. It appears that for various tuna stocks this cryptic component may be of major importance; it may temporarily overestimate the exploitation rate of tuna stocks and subsequently overestimate the interaction between fisheries. A biological classification of the various tunas species, from tropical (e.g., skipjack) to temperate (e.g., bluefin) is developed and discussed. Each tuna species has developed a specific type of migratory pattern between the spawning and feeding zones. The migratory patterns appear to be of key importance in producing various types of interactions.

The various types of interactions, in the short term and in localised areas, and in the longer term (yield per recruit) are also reviewed and discussed in this paper. Various interaction problems still pending are discussed, such as the specific problem of interactions in fishing areas located in the extreme range of the stock distribution, or the interaction problems in relation with the possible homing behaviour of spawning tunas. This homing behaviour may be an important biological characteristic for various tuna species such as yellowfin, bluefin and possibly bigeye. The types of interactions observed or suspected between the Atlantic tuna fisheries are reviewed for all tuna species. Although the problem of interactions was never explicitly discussed by the scientists of the International Commission for the Conservation of Atlantic tunas (ICCAT), it appears clearly that large potential interactions probably exist in the Atlantic Ocean for various tuna species. However, due to the heterogeneity and complexity of the interaction problems, it appears that most of the present interaction results are still preliminary and hypothetical. These uncertainties and difficulties found in the Atlantic Ocean are probably similar to the ones encountered in most other oceans.

1. INTRODUCTION

The tuna fisheries in the Atlantic Ocean have shown an increase in activity since the early 1960s. This is well shown by the global increasing trend in the catches observed for the major tuna species (Figure 1); the increased catches are the consequence of increased effort. This increasing trend was observed to various degrees for most species, except albacore and western Atlantic bluefin (Figure 2). The analyses conducted every year by the Standing Committee for Research and Statistics (SCRS), the ICCAT scientific committee, have also indicated that most of the Atlantic tuna stocks have already reached a stage of full exploitation and some are considered overfished. In such conditions, it is quite clear that the problem of interactions between the various tuna fisheries should be of increasing importance. The interactions studied in this paper will be the potential effects of one fishery on the potential catches and catch rates of other fisheries, catching tuna in the same area or in different fishing zones. The problem of interactions between fisheries is of a general nature, as described by Ricker (1958), but the tuna fisheries and tuna stocks are probably a peculiar case, primarily because of tuna migrations, the wide areas covered by most stocks, and the diversity between the various gears catching various ages of tuna.

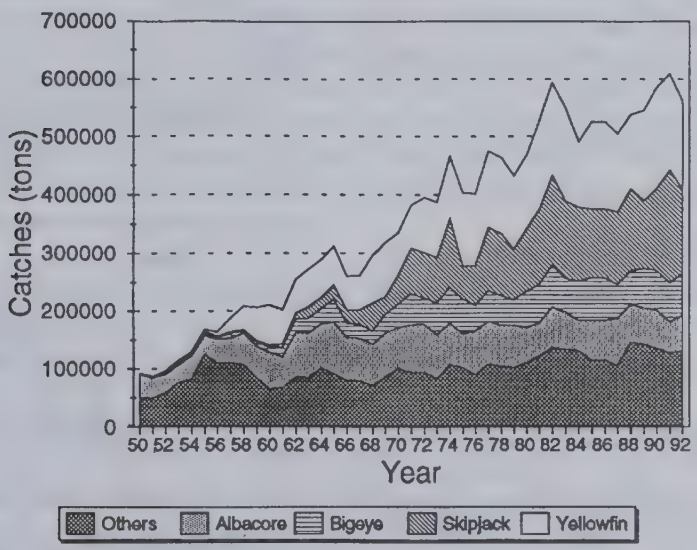


Figure 1. Catches of tuna fisheries in the Atlantic Ocean.

As a high exploitation rate is always a key factor involved in the interactions between fisheries (Shomura et al., 1994), the increasing catches may also increase the interactions between the Atlantic tuna fisheries. However, the SCRS of ICCAT has paid very little attention to the problem of interactions between fisheries. This apparent lack of concern by ICCAT may be that, in the Atlantic Ocean, very few developing coastal countries are catching tunas with an artisanal fishery. As a consequence, fishery managers rarely pressure ICCAT to pursue interaction problems.

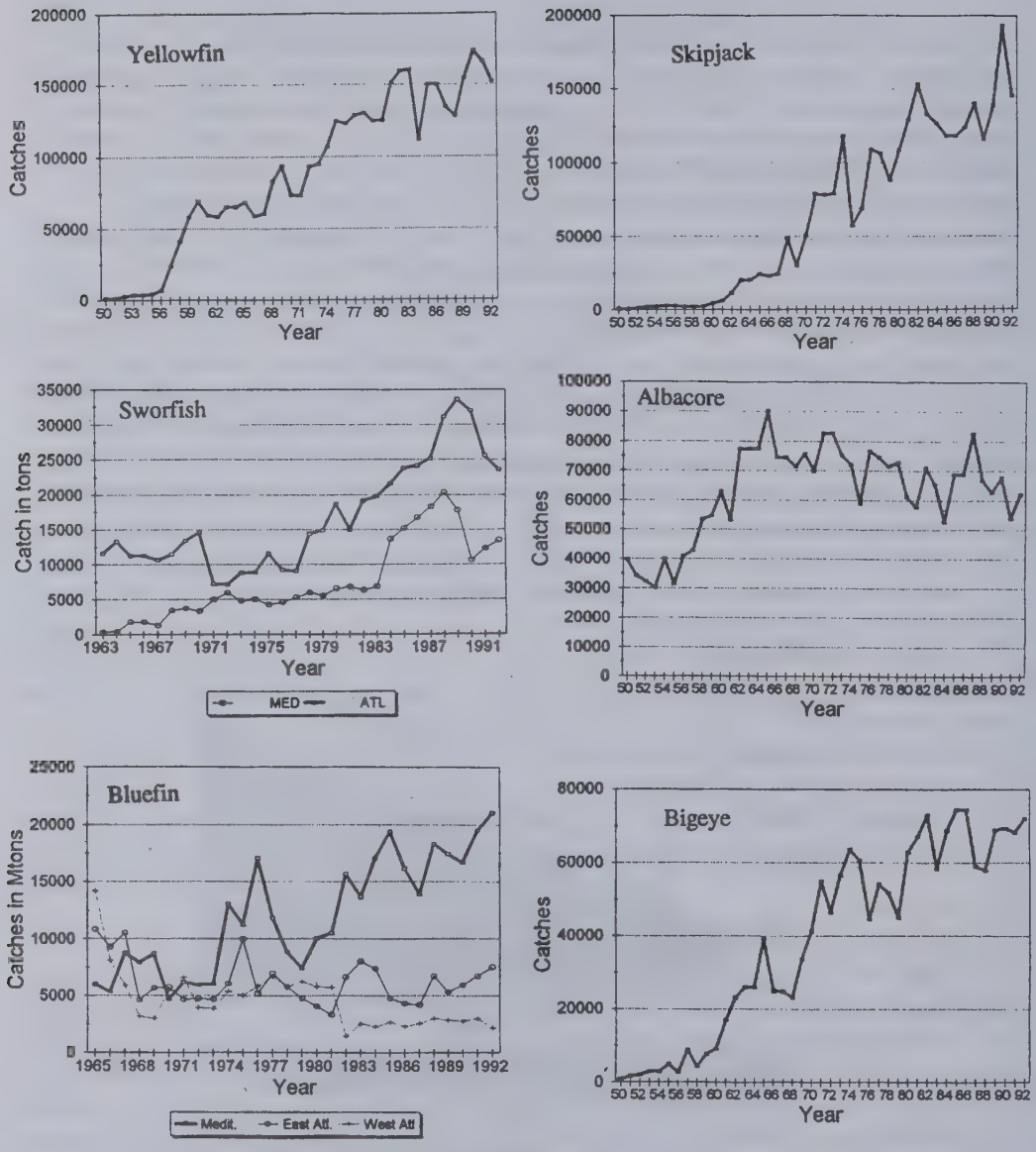


Figure 2. Catches of the major tunas and swordfish in the Atlantic Ocean.

Interaction problems are indirectly tackled by the SCRS at a global and wide scale, using multi-gear yield per recruit models (Ricker model). In this type of model, the fishing mortalities of each gear are first calculated (following VPA and based on the catch by age for each gear), and then the potential for yield per recruit competition between gears are calculated. This type of analysis has been conducted since the early 1970s on yellowfin tuna (Lenarz, 1971), and more recently applied for other tuna species. However, this global yield per recruit analysis (conducted under a hypothesis of a homogeneous unit

stock) is unrealistic for tuna and tuna-like species. For instance, it is now obvious that in the Atlantic Ocean (and probably in all other oceans) the gear yield per recruit analyses conducted on yellowfin caught by the purse seine and longline fisheries do not realistically reflect competition between the two gears. These analyses always indicate that the longline fishery should provide a better yield per recruit than the purse seine fishery, when the real fishing performances of the longline gear is always quite limited. Fishery data from all oceans show that longline gear is inefficient to catch large amounts of yellowfin, at least compared to purse seines.

Very few stock assessment models or, more generally, stock assessment works targeting potential interactions between fisheries have been presented for the Atlantic Ocean and discussed by the SCRS. However, this type of modeling could be well addressed in the Atlantic, at least for some species. The basic data, which are always of key importance in those analyses, are the detailed catch by size and effort data by gear statistics (by detailed time and area strata). These data are available in the ICCAT database for most tuna species. However, the interaction analysis often requires significant tagging of tunas in order to provide realistic evidence of interactions. Preferably, the results should include good recoveries as a very low recovery rate is, most of the time, impossible to interpret. Tagging programs have been conducted in the Atlantic, but only on a limited scale since the general lack of funding in ICCAT during recent years has limited tagging programs. Most of the Atlantic tagging experiments were conducted many years ago, under different fishing conditions and often with low exploitation rates. The results of those studies may be difficult or impossible to extrapolate to the present fisheries and stocks. Furthermore, the various limitations of tagging and recovery data imply that complementary methods such as genetic studies or microchemistry of bones should be conducted to evaluate better the true stock structure of tunas.

The goal of this paper is to develop some general thinking on the interaction problem between tuna fisheries at a world-wide level, and then to examine the present interaction problems, or potential problems, for the major tuna species caught in the Atlantic.

2. GENERAL THINKING ON TUNA INTERACTION PROBLEMS

2.1 General Thinking on Tuna Migrations

Tunas are a world-wide distributed family. Various genera and species from this family have a common biological feature of being "highly migratory". This biological feature has been introduced in the Caracas Law of the Sea meetings, giving to this family a special status in the basic Law of the Sea text (Article 64). The text notes that fishes classified as highly migratory should be managed outside the national EEZs because of their highly migratory patterns. Fish migrations in general and tuna migrations in particular have been extensively described and analysed by many authors, including for the Atlantic Ocean papers by Harden Jones (1981), Cayré et al. (1988) and Cayré (1990).

Based upon the biological cause and type of movement, most tuna migrations can be classified into two categories as "feeding migrations" and "spawning migrations". The extent and types of those migrations vary between species. However, the term "migration" has been often used in an inappropriate manner to describe any movement of tunas; a good

scientific definition should be much more restrictive than the general concept of migrations used by lawyers in Caracas.

The types of tuna movements can be described as "advective" or "diffusive". The "migration" *sensu stricto* corresponding to an "advection type" movement, is a massive and oriented movement towards a biological target, such as a spawning ground or a feeding ground. The homing behaviour often observed for migratory species that show a strict fidelity to spawn in their area of birth belongs to this category. This definition could, for instance, well be applied to southern bluefin tuna migrating, year after year, from their spawning zone south of Java to specific feeding zones of the southern oceans (Figure 3).

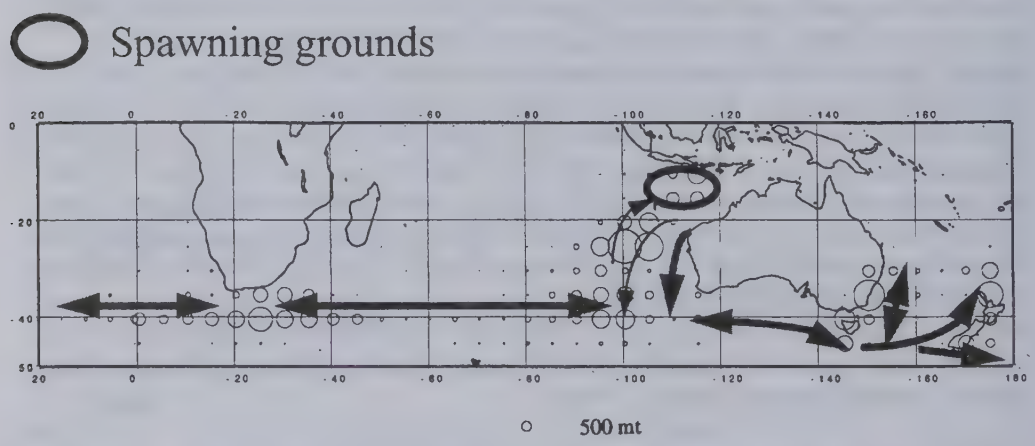


Figure 3. An example of migrations between feeding and spawning areas : the southern bluefin case. Average southern bluefin catches by the longline fisheries during the historical period (average 1956-78). The areas with high average catches correspond to show the sub-equatorial spawning areas (south of Java) and the feeding areas (southern latitudes).

A "diffusion" type movement is a movement of tunas within their ecologically favourable zone. As this favourable zone may often show a seasonal movement in various fishing zones of the Atlantic (for instance in the Senegal area, Figure 4), this seasonality of the environment often produces a massive seasonal diffusion of the tunas, inside the favourable zones. This diffusion usually follows the apparent geographical displacement of their ecologically favourable environment (for instance the 22°C isotherm for tropical tunas, or the 18°C isotherm for albacore).

The time and space heterogeneity of the environment plays an important role in most of those tuna movements. Both the global movement patterns of tunas and their variability, are under the control of the environmental conditions, because the time and areas strata favourable for spawning and for feeding are limited and variable in time and space.

However, it appears that the physiological adaptations of the various tunas species to the environment, especially the thermoregulatory devices developed by most tuna species, are quite different (Sharp, 1978; Brill, 1994). Consequently, each tuna species has developed a specific physiological and ecological strategy. This diversity of adaptive physiology has allowed the tuna family to colonise most parts of the epipelagic zones of the world oceans. These evolutionary and ecological components may play an important role in the exploitation of those stocks, for stock assessments by scientists, understanding the interactions between and among fisheries, and for the management of the tuna resources.

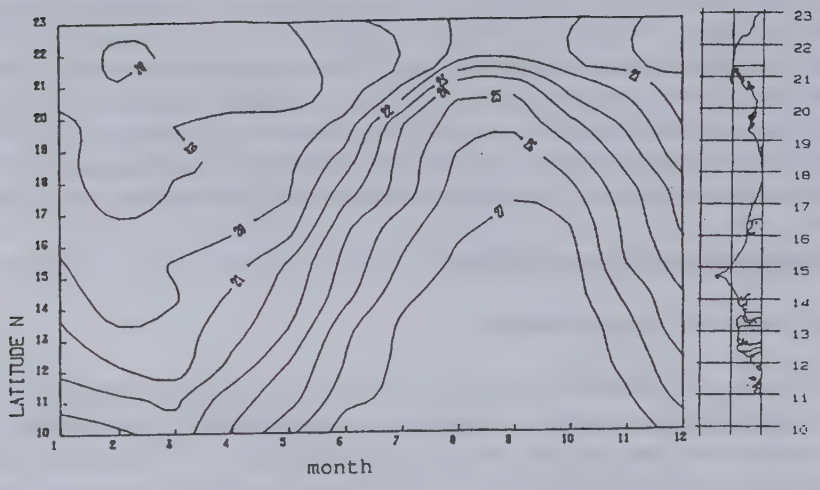
2.2 Tuna Stocks and Cryptic Biomass

2.2.1 The concept of cryptic biomass

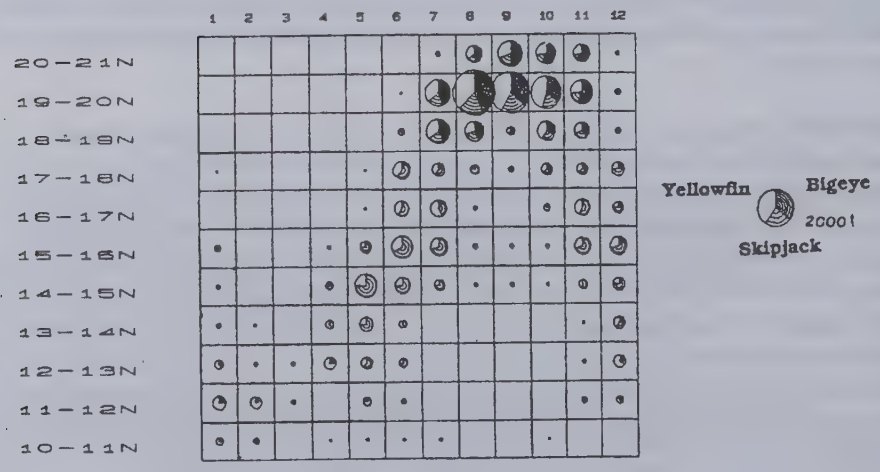
A major biological characteristic of most tuna stocks is that their distribution and movements cover wide geographical pelagic zones. Consequently, most tunas have in common, most of the time, a large potential "cryptic biomass", i.e., a fraction of the stock which is not available to the existing fisheries. This non-available biomass may simply be due to the large oceanic distribution of most of the tuna species; the distribution is often wider in volume (horizontally and vertically) than the strata exploited by the fisheries. This "cryptic biomass" with low exploitation rate shows, most of the time, an incomplete mixing with the biomass in the exploited area. The same problem may be found either geographically (Laloe, 1989; Die et al., 1990), or vertically (depth stratification) when the species exploited by surface gear also inhabits the deep layers of the oceans as is the case with most large tunas. Consequently, the cryptic biomass is either stable or decreasing moderately, in comparison with the heavily exploited fraction of the stock located in the main fishing zone.

This cryptic component may disappear when the fisheries extend their range of operation vertically and geographically. However, a situation where 100% of the total biomass is available to the fisheries may be quite rare, as most tunas cover large oceanic zones and are scattered between the surface and deep waters. Not accounting for this cryptic fraction of the stocks may have been responsible for a major component in error by scientists in their stock assessment analyses; multiple examples of this error can be found for various species in various oceans. The consequences of this error was that, when a tuna fishery starts to develop in coastal areas, the scientist tends to conclude (a) from production model studies the stock was reaching its MSY and the fishery was at its optimal effort and (b) from tuned VPA studies the level of fishing mortality was already high in relation to the low recruitment level.

These erroneous conclusions can easily be explained by the fact that, within the heavily exploited coastal area, (a much smaller area than occupied by the total stock), the potential productivity is smaller than the productivity of the stock would provide, thus the local abundance decreases very quickly as does the local CPUE under a local high fishing pressure (Boggs, 1994; Fonteneau, 1991).



(a) Average sea surface temperature in the Cap Vert area (source: merchant ship data).



(b) Average monthly baitboat catches in the Cap Vert area, by 1° of latitude.

Figure 4. Example of diffusion seasonally driven by the environment: seasonality of tuna fisheries and local sea surface temperatures in the area of Cape Vert (Senegal, period 1980-91). Yellowfin, skipjack and bigeye tunas being caught primarily in warm waters (in the area with sea surface temperature $>24°C$), are forced to migrate seasonally in relation to the marked seasonality of the environmental conditions.

2.2.2 Working hypothesis: "A tuna stock is not a swimming pool"

In a swimming pool, a person located in any place around the pool, equipped with a small bucket will be able to remove all the water from the swimming pool. The volume of water removed from any place in the pool will correspondingly decrease the level of water everywhere in the pool (Figure 5 a). If a tuna stock was similar to the water mass in a swimming pool, any localised fishery could be able to produce an over-exploitation of the total stock; this was never observed for tuna fisheries.

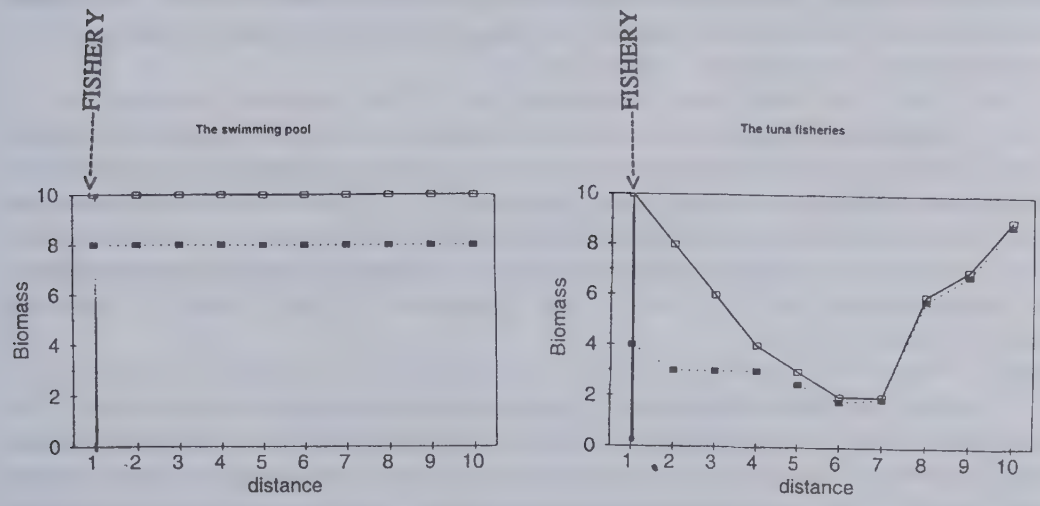


Figure 5. Why a tuna stock is different from a swimming pool? (a, left) The decrease of water level in a pool when water is taken at any site of the pool. (b, right) Changes of relative local biomass when a fishery exploits a given geographical fraction of the tuna stock (in this case, the left fraction of the stock).

In a tuna stock, covering large oceanic areas, most fishery data show that, when a fishery operates only in a small fishing area, its catch decreases the overall stock biomass much less than the biomass within the fishing zone itself (Figure 5 b), corresponding to a local depletion of the biomass. As an example of this fundamental rule (still hypothetical, but probably a realistic assumption for most tuna stocks), the local biomass of Atlantic swordfish will be more depleted inside the US EEZ, which is intensively fished, than in the unexploited central Atlantic, where significant biomasses of swordfish are also found. Based on the Japanese longline catch statistics, a significant biomass of swordfish exists in the central Atlantic but is little exploited for economical reasons. This difference is due to the incomplete mixing of the various fractions of the stock between those two areas, at least in the short and medium time periods. It is a common feature for most tuna stocks that

only the areas with higher densities of tunas, and the areas more easily reached by the fishing vessels, are fished significantly. Unknown and potentially large fractions of the stock thus often remained unfished. The relative importance of this unexploited fraction of the stock may be a function of various factors, including:

(a) *Economics*: Areas of low densities are not exploited for economic reasons. As an example, most albacore stocks will have a greater fraction of their stock unexploited than bluefin tuna, primarily due to lower fishing effort relating to the lower value of albacore. Most albacore stocks can only be exploited by longliners in the strata with high densities. On the contrary, fishermen can exploit bluefin tunas at low fish densities and still make a profit because of the high value of bluefin in the sashimi market.

(b) *Gear limitations*: When the gear available to catch a species is not very efficient (this is often the case with the gear catching albacore), various fractions of the stock may remain unavailable. This component may be changed by improvements in fishing technology (e.g., size of vessels, electronics, etc.).

(c) *Concentration*: Ecological factors, such as the dispersion and concentration patterns of the species and stocks are important factors in determining the unexploited fraction of the biomass. A scattered biomass is always more difficult to catch than a concentrated one. It is well known that all tunas stocks have relatively low biomass per unit area due to the large zones they inhabit. Thus, the average density is always quite low and the resource can be fished economically only when fish are concentrated in specific areas, e.g., in feeding or spawning zones.

(d) *Mixing*: When the mixing rate is high and permanent between the various geographical components of the stock, the stock may become extensively exploited and the cryptic fraction of the stock may be insignificant. This case (similar to the swimming pool concept) seems to be quite rare, or even never observed, for tuna stocks. In most cases, the mixing seems to be quite incomplete (horizontally and vertically) and consequently the effects of any localised fishing is more apparent at a local scale (for instance, within an EEZ) than at the global scale of the stock. This hypothetical rule was implicitly accepted by Hilborn and Sibert (1986) when they discussed the EEZ management of skipjack in the Pacific Ocean. Various existing migration models which can simulate the migratory pattern of tunas exploited by various fisheries (e.g., the models of Kleiber and Baker, 1987, or Deriso et al., 1991) could be used to evaluate this fundamental problem.

2.2.3 Interactions and exploitation rates

Where a moderately exploited stock is considered overexploited, most calculations of interactions between fisheries would conclude that there is a significant potential for interactions because of the high exploitation rate, which is always a key component producing the interactions. In fact, the true fishing mortality may still be quite low and the total population very large, so the potential for interaction may be lower than calculated.

When the fishery develops horizontally (extended fishing zones) and vertically (for instance, by developing the use of deep longlines), the stock assessment analysis provides much revised estimates of the MSY, optimal effort and recruitment level. These three

parameters are generally dramatically higher than the original estimates. The changes of the yellowfin tuna fisheries have been well analysed and modelled by Die et al. (1990) and Laloe (1989) for the eastern Pacific and eastern Atlantic, respectively. Under this development of the fisheries leading to a fully exploited stock, the revised estimates of MSY (and other parameters such as F) are improved estimates of the stock parameters, and estimates may then be converging toward the true parameters of the stock.

The opposite bias and error can also be observed when a fishery, after a period of overfishing, shows a decreasing trend of its fishing effort which is often associated with a decrease in the range of the fishing operations. This case is quite rare presently, but may be observed for species such as albacore. As noted earlier albacore are difficult to catch with modern fishing gears or are not sought due to market reasons (too low value). In such a case, the reduction of the fishing zone may tend to produce an "artificial over-exploitation", with decreased MSY and decreased recruitment levels. Such a situation is due to the reduction in size of the fishing area; the decrease is not due to a stock collapse.

The changes in the estimate of MSY and recruitment levels should not be interpreted as biological changes in the exploited stocks. For instance the increased recruitment calculated from VPA studies in the early 10970s for the eastern Pacific and eastern Atlantic yellowfin fisheries were probably linked with an expansion of the fishing effort targeting those resources. A careful review of the scientific literature in the field of tuna stock assessment may show other examples of this type of apparent changes in resource dynamics.

Consequently it should be very important to estimate the volume, age composition and distribution area of the cryptic biomass in order to make accurate stock assessment estimates and to identify the importance of interaction. The movement patterns of tunas between the unexploited and exploited fractions of stock should also be estimated, as the role of this cryptic biomass will be very important when mixing is relatively low; on the other hand the cryptic biomass may be neglected when the mixing rate between areas is intense and permanent.

2.3 Biological Classification of the Major Tunas

2.3.1 General patterns

Tunas belong to a family which shows well how a systematic group can develop an evolutionary diversity starting from a common root. This common root of tunas originated in the warm tropical waters of the Miocene and Pliocene eras, more than 10 million years ago. Most tuna species have retained some aspects of their geological origin such as their tropical locations for spawning areas and nurseries.

Additionally, most tunas have developed thermoregulation capabilities (Sharp, 1978; Brill, 1994); this thermoregulation is due to various sophisticated anatomical features which are specific to tunas. The range in efficiency of thermoregulation is, however, variable and dependent on size, as thermoregulation facilities are proportional to size. While all tuna species are able to colonise colder waters when they become larger, the ability to swim deeper and/or at higher latitudes is dependent on size.

Based on size and thermoregulatory capabilities, tuna can be classified into three groups (Figure 6). These are:

Group A includes tropical species, such as skipjack tuna and *Auxis* spp. The species included attain small maximum size and are predominantly distributed in warm waters (>22° C) during their entire life.

Group B includes tropical-temperate tunas such as yellowfin and bigeye tunas. These tunas show extensive migrations between their spawning areas in equatorial waters and their feeding grounds in the southern and northern latitude. This biological pattern is especially true for adult bigeye which are distributed deeper and at more temperate latitudes than yellowfin .

Group C includes temperate tunas such as bluefin tunas. These tunas show very extensive migrations between their spawning areas located predominantly (but not always) in warm waters, and their feeding grounds which are located in temperate or cold waters.

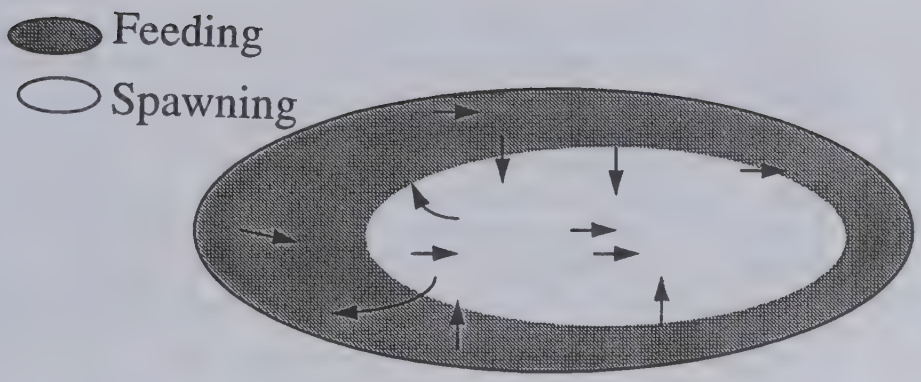
2.3.2 Biological characteristics of tuna species

Figure 7 summarises the thermoregulation pattern for the various tuna species. The tropical tuna species of Group A are predominantly of small size (usually less than 5 kg), have high natural mortalities (M near 1.0), short expectation of life (less than 5 years), and consist of large numbers of individuals recruited yearly in their populations (in the order of billions of fishes).

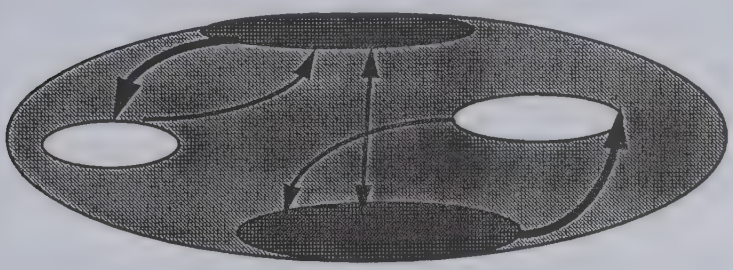
On the other extreme, the temperate tunas of the Group C (their prototype being the bluefin tunas) show opposite characteristics. These include large adult sizes (reaching often 500 kg), low natural mortality (at about M=0.2), long expectation of life but late spawning; usually after 5 years, and small numbers of fishes recruited yearly (hundred of thousands yearly).

The intermediate Group B (yellowfin, albacore and bigeye) show intermediate characteristics for all those biological parameters. The three group show a striking similarity in the relative distributions of their feeding and spawning areas (Figure 6).

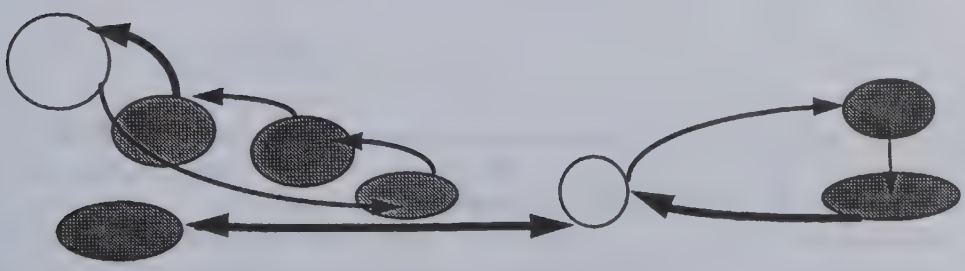
Group A (tropical tunas), is distributed in large tropical areas suitable for them to spawn and to feed. Spawning often occurs all year round in most warm waters areas; areas where the tunas encounter conditions suitable for sexual maturation. Maturation of these tunas is usually very fast and spawning is generally opportunistic. As those areas are often poor feeding grounds, the species in Group A often move towards the colder and richer subtropical areas, adjacent to the spawning areas, where they can temporarily feed better and grow faster than in warm equatorial waters. This group of tunas show predominantly diffusion type movements.



(a) Group A. Diffusion-type movements, latitudinal and longitudinal, in a non-stationary, environmentally-favourable zone. A large, equatorial spawning area that is slightly smaller than the area of distribution.

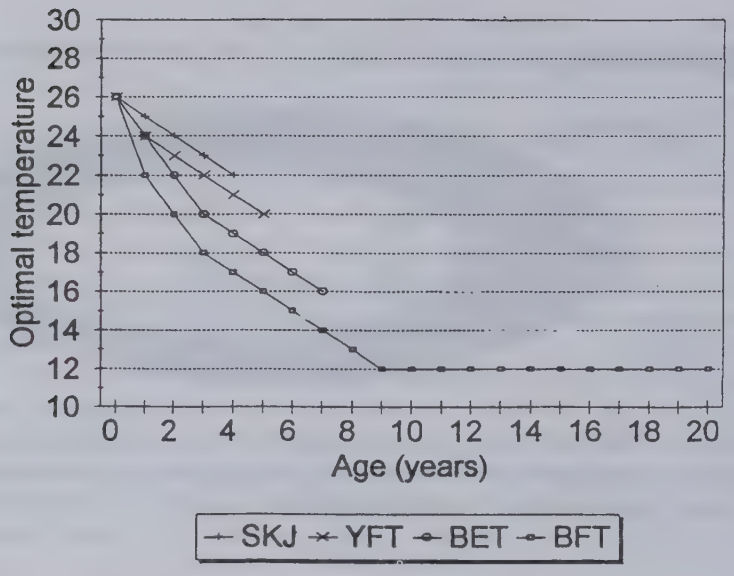


(b) Group B: Large but specific equatorial spawning areas, and large migrations of adults in subtropical and temperate waters (often deep).

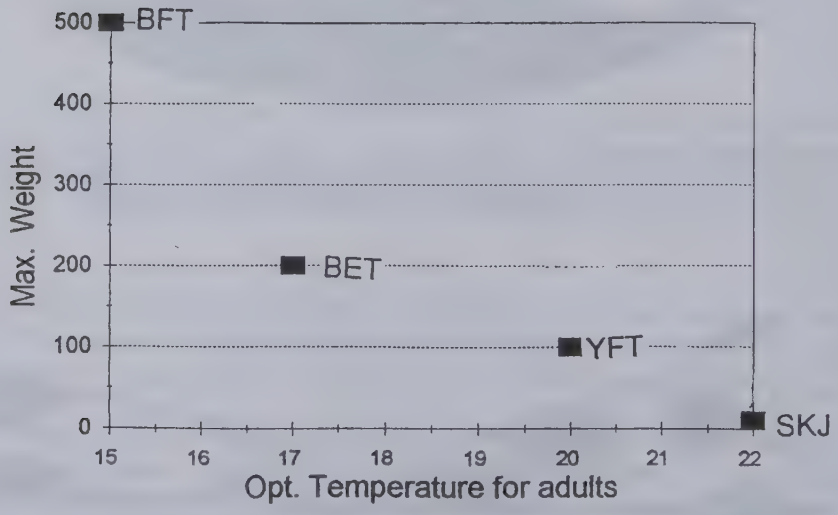


(c) Group C. Dislocation between warm subtropical spawning areas and remote temperate feeding areas. Precise migratory behaviour and strict homing, between small spawning sites and temperate or subpolar feeding areas.

Figure 6. A simplified ecological classification of tunas: spawning and feeding zones.



(a) Schematic overview of the changes of optimal water temperature for various tunas, versus their age (BFT=bluefin, BET=bigeye, YFT=yellowfin, SKJ=skipjack).



(b) Schematic overview of the approximate minimal sea water temperature for various tuna species, versus the maximum weight of each species and the average levels of recruitment (BFT=bluefin, BET=bigeye, YFT=yellowfin, SKJ=skipjack).

Figure 7. Major biological characteristics of various tunas species.

Group B (yellowfin, albacore and bigeye) shows more geographical segregation (in time and space) between their original spawning grounds and the northern and southern (or western/eastern) feeding grounds. Spawning takes place usually in specific equatorial areas during limited periods, when mature fish are concentrated for spawning. Feeding grounds for the adults may be located at great distances from the spawning areas; those tunas may spend a large proportion of their life cycle outside the spawning zone. Massive and large scale migrations often takes place between the spawning and feeding grounds covering hundreds or thousands of miles; this extensive movement is well shown for instance for the Atlantic yellowfin (Figure 8). Similar large scale movement may occur with yellowfin in the Indian Ocean.

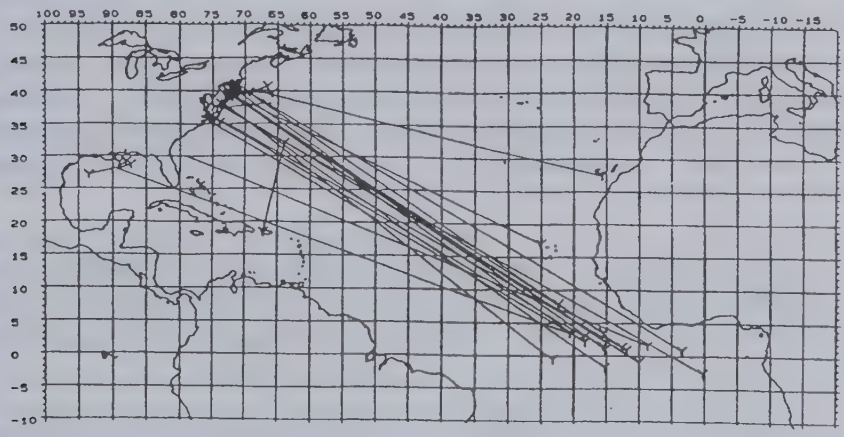


Figure 8. The transatlantic migrations of yellowfin tunas between feeding zones (west Atlantic) and spawning zone (Gulf of Guinea) shown by transatlantic recoveries.

Group C (bluefin) represents the most extreme case of "geographical dislocation" between the spawning and feeding zones. Spawning usually takes place in warm waters, but always within very specific time and area strata. The bluefin will spend most of its life outside the spawning area; they are the only tuna able to feed in the remote and rich cold waters of the northern and southern temperate areas. This biological behaviour definitely implies a strong homing behaviour. The southern bluefin tuna has adults scattered in the Indian, Pacific and Atlantic Oceans and spawns south of Java. This species must have an efficient homing behaviour in order to return in due time to their remote birthplace from far distant places. The same situation will apply to the other bluefin tunas (Atlantic and Pacific). All bluefin tunas stocks probably offer various examples of strong homing behaviour which provide good examples of the "obstinate nature" in migrations as developed from an evolutionary point of view by Cury (1994), it is clear that the bluefin tunas should have a consistent and strict spawning fidelity in order to be able to reproduce efficiently in a precise short time and area window. Group C, and to a lesser degree Group B, provide the best examples of the "true" tuna migrations which involves massive and directed movements.

In summary, the small tropical tunas in Group A have developed a biological strategy which involves hundred of millions of small individuals exploring, more or less randomly, the entire warm inter-tropical area, feeding and spawning on an opportunistic basis, and following the seasonal movements of inter-tropical warm waters.

Large temperate tunas in Group C have developed an opposite biological strategy where small numbers of very large tunas are able to migrate over great distances and to explore and exploit efficiently the cold northern and southern temperate feeding areas. The species use their larger size for better thermoregulation and more efficient migrations. This strategy will necessarily imply from an evolutionary point of view an efficient capacity to return to their individual tropical birth strata ("homing"). This is a necessary key to the survival of those species.

The species in Group B show intermediate life strategies in terms of number of individuals, maximum sizes attained and migrations between spawning and feeding zones. The homing component in group B may also be an important component. However, the advective and diffusive components in their movements may vary between oceans (the spawning migrations are not well known for the yellowfin in the eastern Pacific) and more research should be conducted on this important topic.

The strong homing behaviour for some tuna species may have been neglected by tuna scientists. This homing behaviour may have definite implications in stock assessment and management of various heavily exploited tuna stocks, such as most of the bluefin stocks and possibly some of the other species.

It may consequently be of major importance to better estimate the genetic heterogeneity within each stock (or management unit), know the fidelity of specific groups of tunas to given migratory patterns and consequently the potential interactions between fisheries located in various areas and to determine the fidelity of each sub-population to its birth strata (homing).

3. GLOBAL CLASSIFICATION OF THE TUNA FISHERIES INTERACTIONS
(based on experience in the Atlantic Ocean).

3.1 Atlantic Tuna Fisheries: Data, Fisheries and Environment

Very few tuna interaction problems can be considered as being ocean-specific. However, various features in the Atlantic may be quite unique and help facilitate interaction studies. The features include:

(a) the small size of the Atlantic Ocean, which is more or less a closed geographical unit and covers only 90 millions square km;

(b) tuna fisheries have shown a strong development during recent years, starting from more or less virgin stocks, to fully exploited fisheries (see Figure 1);

(c) an oceanographic environment which has been well studied by various oceanographers; the Atlantic is characterised by a strong seasonality in most areas (temperate, tropical and

equatorial) and a low interannual variability; the Pacific, on the other hand, shows low seasonality and marked year to year variability (El Niño).

The following section will review some aspects of interaction between the Atlantic fisheries.

3.2 Long Term Interactions

The problem of recruitment overfishing , or how overfishing can affect the recruitment levels, is an important aspect of interaction. It may explain how overfishing the spawning stock may reduce the recruitment levels and the potential catches of another fishery directed to catching juveniles. However, the typical stock recruitment model, such as the models proposed by Beverton and Holt (1957) or Ricker (1958) do not apply to tropical tunas, at least for most tropical species. For these species it seems that the variability in recruitment is only moderate from year to year. No trends are apparent even at high levels of exploitation of the adult stock as experienced in the Atlantic (ICCAT, 1994a). In fact, a decreasing recruitment trend due to overfishing (recruitment overfishing) has never been observed for any tropical tuna, even for highly exploited stocks.

Consequently the present paradigm for Atlantic tropical tunas can be that, at moderate or relatively high level of fishing efforts, there will not be any effect or interaction of the adult fisheries on the juvenile ones. This specificity of tropical tunas may be related to the extremely high fecundity of these individuals (female yellowfin, skipjack and bigeye spawn several millions of eggs, several times each year). Spawning takes place over extensive areas and periods of time, where the larvae can always (statistically) find good conditions for their survival. In such wide scale conditions suitable for tropical spawning, recruitment will be limited by the carrying capacity of the large nursery areas or by environmental variability, rather than by the size of the spawning stock .

Temperate tunas, such as bluefin, may be quite different, as it is well shown by the decreasing trends of bluefin recruitment in the western Atlantic or in the southern bluefin tuna stock. The decrease in recruitment is probably a consequence of very reduced spawning stock size. The existence of spawning areas which are quite limited geographically and seasonally, and often very far from the feeding grounds, may be a dangerous component in the life cycle of those species.

The conclusion is that overfishing may have little or no negative effects on the fisheries catching juveniles of tropical tunas, but that this interaction may represent a real danger for temperate tuna. This danger of competition is of key importance, as the future of any stock relies on its recruitment level.

3.3 Medium Term Interactions

The medium term interaction addresses two different questions. These are (a) the extent fisheries catching small or medium size tunas affect fisheries catching large tunas, and (b) how longline and purse seine fisheries share the biomass of large tunas.

3.3.1 Interaction between fisheries catching small or medium size tunas, and fisheries catching large tunas

The first type of interaction (a) is directly a yield per recruit problem at the level of a stock (Ricker, 1958). It concerns all species which are exploited at a smaller size by surface fisheries and at a larger size by other fisheries. All tuna species with a large potential of growth (e.g., yellowfin, bigeye, bluefin, albacore) which can be caught at small sizes or at large sizes by various gears are potentially concerned by this type of interaction. The Atlantic Ocean offers good observations and relevant analysis since a good statistical database is available from this ocean through ICCAT. In the usual multi-gear yield per recruit models, a stock unit is accepted as an assessment and management unit. The fishing mortalities of each gear are first calculated under this hypothesis (following VPA and based on the catch by age for each gear), and then the potential for yield per recruit competitions between gears can easily be calculated.

This type of study, based primarily on the analysis of fishery data, is quite simple to conduct when detailed fishery data are available. However, they are usually heavily dependent of various parameters and conditions:

- The quality of catch statistics for the small fishes, especially the correct species composition of the catches. These "correct statistics" may often be difficult to obtain as it is difficult to estimate the actual quantities of small bigeye and yellowfin tunas caught by most fisheries. When the catch data are an order of magnitude incorrect (as it was often the case for juvenile bigeye tunas) all subsequent interaction analyses would be biased. Also, correct data on discards are often difficult to obtain but may be of significant importance in various fisheries, for instance with the development of fisheries associated with natural and artificial logs (where large amounts of very small tunas are often discarded).

- The exact nature of the stock structure and its year to year variability, including the existence of specific migratory routes between fisheries, intensive or low mixing rates between fishing areas, and effects of the environment on migrations. These biological parameters linked to the tuna migration and to their environment are partly described and categorised in Section 2. A more detailed analysis of these phenomena would require specific and *ad hoc* studies in each ocean and for each species.

- The natural mortalities M assumed for the juveniles. This factor may be of key importance in the interaction studies as the numbers of small individuals caught are often known (depending of the fishery statistics), but not the true numbers of small fish in the sea (recruitment). The yield per recruit calculations will be (most of the time) quite sensitive to this variability of M during the early life of the fishes. As most often M is a poorly known parameter, especially for juveniles which are entering in the fisheries, this problem may be of key importance to evaluate the potential interactions between juveniles and adults tunas fisheries.

On this topic of the possible changes in natural mortality with age, some general biological considerations should be kept in mind, even when data are inadequate to allow

calculation of a reliable M at age. These the biological considerations may be of two categories:

Tunas in the same ecosystem at the same size should have similar natural mortalities.

This "reasonable" argument has been accepted since the early 1980s as a working hypothesis by the SCRS scientists. The hypothesis is that, within a plurispecific school of skipjack and juveniles bigeye and yellowfin tuna, the M of each species is very similar. Following this argument, it was accepted by ICCAT scientists that the M for juvenile bigeye was not M=0.4, as previously accepted, but M=0.8 (i.e., the M level accepted for skipjack tunas). The same rule was also applied for yellowfin tuna, and the juvenile M of this species increased from 0.6 to 0.8 during the first two years of their life. Those changes in the juvenile M has produced changes in the recruitment levels (increased levels), in the yield per recruit and in the potential competitions between fisheries catching juvenile and adults (decreased potential for interactions).

There are at least three general rules in the variability of the natural mortalities of any animal that should be kept in mind:

(1) The individual in their early life are more fragile and suffer a higher risk of natural mortality. This higher risk may for instance be due to a higher risk to be eaten by a predator (including by their own parents) or to die early by natural selection ("natural" death of the weakest individuals).

(2) Natural mortality tends to increase after sexual maturity for most animals. This feature has been noted in terrestrial fields where the natural mortality is more easy to measure (Gompertz, 1825).

(3) Most fishes living in warm equatorial or subtropical waters have a higher M than the individuals of similar size living in the cold or temperate waters (Pauly, 1980).

Following those three general rules, it should be assumed that the juvenile M should be, for most temperate or tropical-temperate tunas, higher than the M for adults. On the opposite side of the life cycle, an increase of M after sexual maturity should also be a biologically reasonable hypothesis. Such an increase of the natural mortality in relation with ageing and senescence is a biological phenomenon commonly observed for most living organisms (Finch, 1990). The higher M for juveniles and older fish may have significant consequences in most analytical tuna stock assessment (recruitment, yield per recruit) and in the potential interactions between fisheries.

As a conclusion, the yield per recruit potential competition between fisheries catching juvenile tunas and fisheries catching adult tunas may be handled by the traditional yield per recruit analysis. However, the results obtained may be very sensitive to the various uncertainties in the data available, the stock structure and the profile of natural mortality by age.

3.3.2 How do longline and purse seine share the biomass of large tunas?

The relationship between fishing effort of purse seiners and longliners, and their respective catches of large fish, shows completely different patterns for yellowfin and bigeye tuna. The potential catches of the longline fishery to catch large yellowfin seems always limited, compared to the catches by the purse seine fishery; the latter uses an efficient and productive gear type (Figure 9). An opposite situation is observed for bigeye were the purse seine is an inefficient gear to catch large bigeye in surface layers, and the longline gear is very efficient to target large bigeye which generally inhabits deeper waters. This differential efficiency of each gear is probably related to the heterogeneity in the vertical distribution of each stock, yellowfin being basically a subsurface tuna, even at large sizes, whereas bigeye is most often a deep-swimming and temperate species at larger sizes.

Consequently, the performances of each fishery and the relative potential of interactions between them cannot be well estimated by the yield per recruit models. In fact this type of model will overestimate the efficiency of longliners on large yellowfin and overestimate the efficiency of purse seiners on large bigeye. However, there are still probably some potential real and direct interactions between the two gears on the adults when they are fishing in the same area: these interactions can be of the "urn" type interaction (cf. section 3.5), in which locally a tuna taken by one gear cannot be taken by the other gear, which gives an advantage to the more efficient gear.

3.4 Short Term Interactions

How do various gears fishing in the same time and area compete "locally" to exploit tuna resources? The answer to this question may be related to the local movement patterns of the tunas.

(a) *The "urn" concept*. When a fraction of stock is temporarily resident in an area, a simple "urn model", assuming no significant input or output of fishes, can describe the local and short term interaction between the local fisheries. Tunas are clearly migratory; however, during limited periods of time, they can very often be considered as sedentary, and assumed to be a locally and temporally isolated fraction of stock. This type of seasonal concentrations are often observed for tunas in various circumstances and sites such as:

Spawning concentrations in offshore spawning areas (such as the yellowfin in the Atlantic and Indian Oceans).

Feeding concentrations in both inshore or offshore areas. Those type of feeding concentrations are often linked with the seasonality of the environmental conditions. For instance in the Atlantic Ocean, the area of Cape Lopez and Senegal offer good feeding opportunities seasonally, and this attracts a large biomass of tunas to the area each year.

Various *islands and sea mounts ecologically* attractive for tunas: it appears from both tagging and fishery data that the biomass of tunas available in the vicinity of islands is often locally resident during some months or even years, depending on the species and environmental variability.

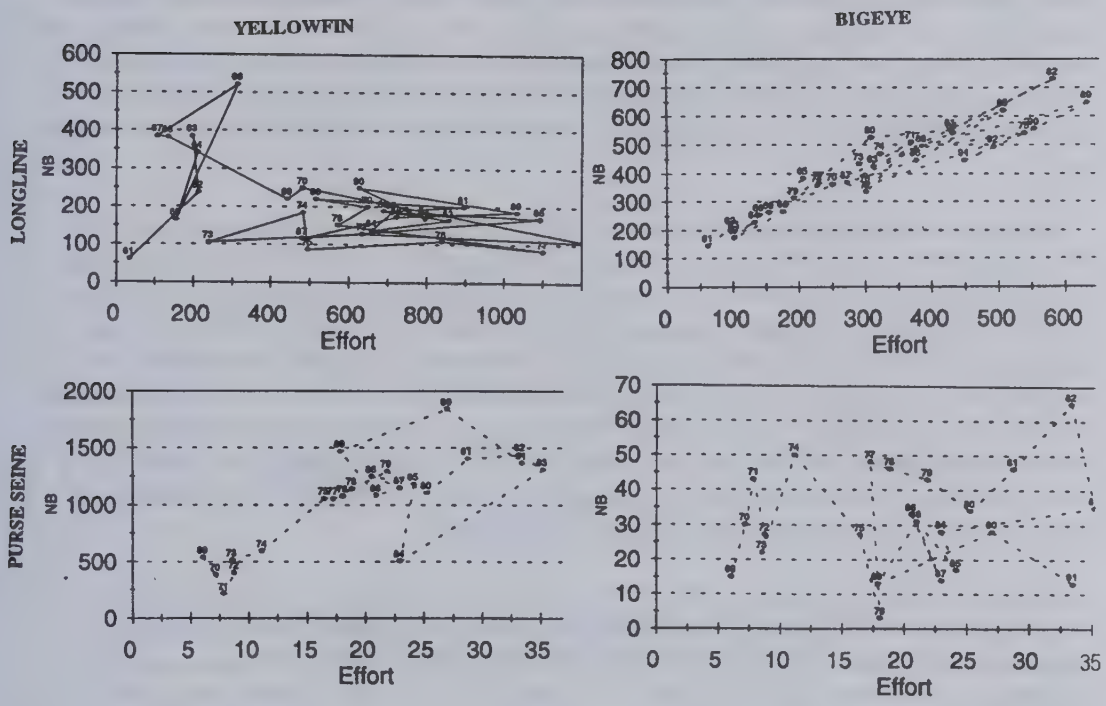


Figure 9. Catches of large yellowfin and large bigeye tunas by longliners and purse seiners and fishing efforts of those two gears in the Atlantic.

When a fraction of stock is stable in this area of concentration (e.g., no emigration and no immigration), the *local interaction problem* becomes quite simple. During limited periods of time, it can be assumed locally that:

- The natural mortality becomes much less important.

- The fishing mortality rates can be easily calculated when the total catches are known, if there is a measure of local abundance (local CPUE for instance). If the local exploitation rate was high, a case often observed upon tuna concentrations fished by tropical purse seiners, the final local catch tends to be the initial biomass recruited in the area (very high local exploitation rate).

In this simple case, the recruitment in the area will be shared between simultaneous fisheries. The potential local catch will simply be the local biomass which entered into the area. Such types of fisheries have been analysed by Boggs (1994) or Fonteneau (1991). The interaction between fishing units will simply depend of the available total biomass and on the relative effort and catch of each gear. This type of competition will be the "competition" of

type 1 as described by Ricker (1975)--the catch of each day by a boat reduces the catches of the other units later. The abundance of fish is lower and lower as the fishing is developing, and the rate of this decrease is proportional to the number of boats. This has been expressed in Figure 10 which is a local production type curve, within a limited time and area stratum. It shows the expected relationship between the local catch during a fishing season and the total fishing effort. In this example the initial biomass and potential catch is 10,000 mt which can be taken only with a very high fishing effort (asymptotic level of the local catches). If a local fishery working on this fraction of stock takes 5,000 mt per fishing season, the addition of a new fleet catching 5,000 mt will significantly reduce the catch rates and total catch of the first fleet.

This type of short term and local competition is well shown in the Atlantic by the catch, effort and CPUE relationship of purse seiners: when the effort is low within small strata, the average CPUE is often high or very high. When the effort and catches are high in the same strata, the CPUE is more often moderate or low. In this case of high local effort, it is clear that there was probably, at least at the beginning of the period, a large biomass which is in contradiction with the low CPUE. The easiest explanation for the final low CPUE, is probably related to the urn concept: the interaction between a great number of boats on a limited local resource will increase the catch, but will reduce the CPUE, more quickly than a small fishing effort. The final CPUE of this large fleet, integrated over a monthly period, will then be an average low (instead of estimating the large initial biomass).

(b) *The "pipeline" concept.* When there is a permanent flow of tunas in an area, for instance a fishery taking place in a migratory route (similar to a salmon fishery during the migration towards spawning grounds), this interaction problem may be well treated as a "pipeline fishery" , with "upstream" fisheries catching migrating tunas which will not be available to the "downstream" fisheries.

In this case, of a permanent "migratory flow" of fishes between two areas, two or more fisheries may be operating in fixed geographical places, on various sites of the tuna migratory route (for instance one upstream, the other downstream). This case may be quite rare for tunas, but may be found for some tuna species in coastal migrations. This type of competition is quite simple to analyse, being similar mathematically to a short term yield per recruit analysis.

4. A REVIEW OF VARIOUS POINTS RELATED TO INTERACTIONS BETWEEN TUNA FISHERIES

4.1 Tagging, Life Cycles and Spawning

It appears clearly that tagging remains the most direct way to estimate the transfer rates of tunas between fisheries and their potential for interactions. However, one should always be aware that movement information obtained from tagging is most often based on juvenile tunas (because of the low probability to recover tagged tunas after long durations for most species), and the data should not be extrapolated to the spawners. This precaution is because of the major physiological and behavioural changes developed by tunas during their life. A good example of this problem was shown recently in the Atlantic yellowfin fishery where, until 1982, a two-stocks hypothesis was assumed, based on the tagging of juveniles. A new "one-stock hypothesis" was developed recently developed from the tagging of medium-sized fish.

Consequently the tagging of adult tunas, or other methods such as genetics or biochemistry of bones (which can potentially keep records of fishes past migration), should be developed in order to evaluate the movement patterns of adult tunas, especially in relation to spawning. These results may be fundamental to estimating most tuna interactions.

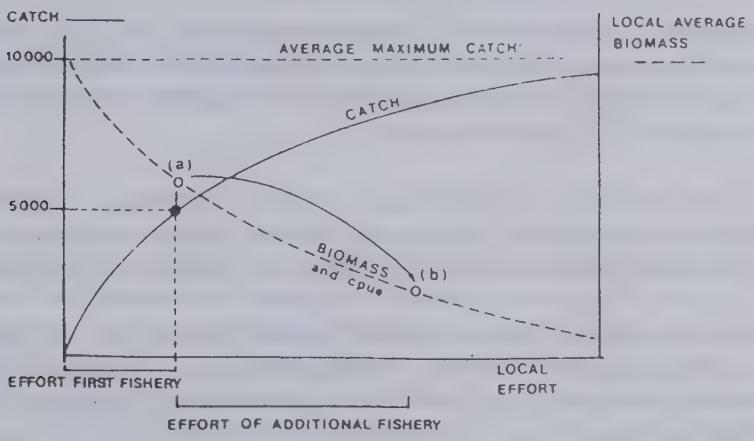


Figure 10. The "Urn model" concept of a temporarily isolated tuna resource (local concentration) heavily exploited by competing fishing units.

4.2 Interactions for Various Tuna Species

The potential for interactions and the nature of those potential interactions are highly dependent of the ecology and life cycle of each tuna species (especially the movement patterns). However, the interactions may be similar in all oceans for a given species. A three-group classification scheme, as developed in Section 2.3.1, with tropical species (skipjack and *Auxis* spp.), tropical-temperate species (yellowfin, bigeye and albacore) and temperate species (bluefin), could well be used as a useful basis to built ecologically similar groups with similar types of life cycles and migrations and similar potential for interactions. It would appear in a first review that the potential risk for interaction is probably more critical for the more temperate species, because of their longer duration of exploited life and larger potential of growth, smaller stock size and probably having more precise migration patterns and a more pronounced homing behaviour.

4.3 Genetic Heterogeneity of Stocks and Fishery Interactions

The genetic studies on tunas are still quite preliminary to make any definitive statement of the genetic structures of tuna populations. However, it can reasonably be assumed as a working hypothesis that the temperate or subtemperate species, may show a significant genetic heterogeneity, each genetic group showing a characteristic migration pattern toward a genetically sustainable unit (sub-population) linked with a strong homing behaviour (which is an evolutionary necessity for temperate tunas spawning in specific subtropical areas). In such

an unusual (for tunas) but realistic hypothesis, the migratory routes of specific fractions of stocks would be of major importance for both the stock assessment and stock management, and more specifically for the potential interactions between fisheries. The studies of the genetic heterogeneity within the tuna populations and stocks should be developed to better understand the various types of fishery interaction.

4.4 Changes at the Stock's Frontiers: Interactions or Environment Effects?

Tuna fisheries, especially those catching temperate tunas, often show striking and unexplained changes in relative abundances and catches. Such examples were observed for bluefin tuna in Canada, Norway and Sweden, and for bigeye in the Azores and Madeira. These changes of CPUE can be explained:

- by the environment, either by changes in the local environment (for instance waters too cold or too warm locally), or changes in the food locally available to the tunas, or by changes in the global environment for instance in remote places of the migratory routes;

- by interactions with upstream fisheries ("pipeline fisheries"), or by a simple decrease in the total stock abundance which often produces for pelagic species a reduction in the distribution area of the stock. In such a case of reduction in the distribution area, a moderate decrease of the stock total biomass can produce exaggerated and dramatic effects on the fisheries operating at the frontiers of the stock. This could create an unexpected and spectacular type of interaction between fisheries.

These potential interactions between a central fishery and a "frontier fishery" may be also related to a sub-population heterogeneity. If a given fishing area in the extreme range of the fishery is a feeding zone for tunas born in a given spawning unit (or sub-population), the overexploitation of this small unit may produce a collapse of a specific fishery localised in a given area of the extreme feeding grounds. This hypothesis of a genetic heterogeneity in the stock could explain why various specific fisheries for adults bluefin vanished entirely in the Atlantic. This hypothesis that the individuals in a given recruitment are not equivalent, and may have their specific migration routes, is quite unusual for the tuna stock assessment, but may be a valid one for tuna species undergoing extensive migrations between certain warm spawning areas and cold feeding zones.

5. REVIEW OF SPECIFIC INTERACTIONS IN THE ATLANTIC

5.1 Small Tunas

The small tuna fisheries catches are reaching an average level of 127,000 mt in the Atlantic (i.e., 23% of the whole Atlantic tuna catches). Those catches are predominantly of *Sarda* spp. (25%), *Scomberomorus* spp. (26%) and *Euthynnus* spp. (17%). Few studies have been conducted in the Atlantic on these species caught by industrial and artisanal fisheries. For most species, the stock structure is completely unknown. However, because of the coastal nature of most of these species, and because of the short distance movements indicated by few recoveries, it would appear that the potential for interactions between fisheries catching small tunas would be limited to the regional or sub-regional levels. In this hypothesis the management of these resources should be conducted at a sub-regional level (e.g., off the Ivory Coast and Ghana, not the entire Atlantic), all the potential interactions between remote

fisheries being assumed to be non-significant. In such a hypothesis, potential interaction may still exist between the various fisheries catching these small tuna species.

5.2 Skipjack Tuna

5.2.1 Fisheries

The skipjack fisheries (Figure 2) in the Atlantic caught an average of 147,000 mt per year during the period 1988-92. These fisheries were located predominantly in the eastern Atlantic (82%), but were also present in the western Atlantic (18%). The main gears catching skipjack tuna in the Atlantic were purse seiners (54% of the catches), and pole-and-line baitboats (45%).

5.2.2 Stock structure

A two-stock hypothesis is usually accepted by the SCRS in conducting skipjack stock assessments (but very little skipjack stock assessment was done during recent years by ICCAT scientists). This hypothesis was based on the geographical distribution of the various age groups caught in the Atlantic. No trans-Atlantic migration of skipjack has been demonstrated from the tagging results, but this result may not be significant, as all tagging was done in the eastern region, while few fisheries were active in the west. In the Atlantic, skipjack tunas show predominantly a large diffusion component in its movement patterns. This diffusion pattern is seasonally driven by the seasonal variability of the environment in the Atlantic, which produces large north-south movements of the skipjack biomass, especially in the eastern Atlantic.

5.2.3 Interactions

The SCRS scientists concluded that the Atlantic skipjack stock was, until now, moderately exploited. Most of the research conducted on the Atlantic skipjack was conducted in the early eighties, especially during the ICCAT International Skipjack Year (1981). The analyses were conducted on the CPUE by sizes of various fleets (purse seiners and baitboats) and on the tagging and recovery data done during this program. The general conclusion of these analyses concerning the potential interactions between the various fisheries was that little interactions should be expected with the fisheries in activity during this time. In fact, because of the low availability of both small (e.g., less than 45 cm) and large (e.g., greater than 60 cm) skipjack to the fisheries, and because of the relatively low exploitation rate of the stock, very little potential interaction should occur, at least between the large areas under study.

However, some interactions at a small geographical scale, between small adjacent fishing areas (for instance between the Ghana and Liberia areas, located at a distance of 1,000 nm, with fish moving freely between the two areas) could happen. These small scale interactions have not been quantitatively estimated. They could probably be classified as "urn type" interactions, with various fisheries competing temporarily to exploit a limited resource, which is stationary in a small geographical area.

5.3 Bigeye Tuna

5.3.1 Fisheries

The tuna fisheries in the Atlantic (Figure 2), caught an average 67,000 mt of bigeye per year during the period 1988-92. The fisheries are located predominantly in the eastern Atlantic between 30°N and 30°S). Three gears are primarily used to catch bigeye tuna in the Atlantic; these include longline (62%), purse seine (13%), and pole-and-line baitboats (12%). Longliners catch only large bigeye, while most baitboats and purse seiners catch bigeye of smaller sizes. An exception should be noted for the baitboat fisheries located in Madeira, Canary and Azore Islands, where they catch large bigeye.

5.3.2 Stock structure

A single-stock hypothesis is used by ICCAT scientists for the stock assessment of this species. The fisheries for juveniles are located in equatorial areas that are different from the areas of adult concentrations; the latter are located near the northern and southern tropics. This observation on distribution is easily explained by the physiology of the species. Young bigeye are physiologically a tropical species, living in surface warm waters. They become temperate and deep-swimming when mature, except during seasonal spawning when they return to tropical waters (Figures 6 and 7).

Very few scientific data are available from tagging of large fishes, or from other sources, to determine the real stock structure of bigeye tunas in the Atlantic. For instance, even the location and time of spawning are not well known. Furthermore, if the present hypothesis of one spawning zone and two major feeding areas (north and south temperate areas) is valid, it is still unclear when the adult bigeye do their spawning migrations toward equatorial areas. It is also unknown if the adults return to their original northern and southern feeding zones after spawning, or if they migrate randomly in any of those two directions. All of these stock structure characteristics may be of key importance in the study of potential interactions between fisheries.

5.3.3 Interactions

Even though juvenile bigeye tuna are quite difficult to recognise from juvenile yellowfin (e.g., Fonteneau, 1975), a systematic scientific sampling of the species composition of small tuna catches has been conducted in the Atlantic on a routine basis since 1979 (ICCAT, 1984). The sampling has provided reasonably good estimates of the numbers of small bigeye landed. The catch of small (less than 80 cm) bigeye taken in the Atlantic since 1955, the beginning of the industrial fisheries, are shown in Figure 11, together with the catch of large bigeye (more than 120 cm). Figure 12 shows the catches of large bigeye by gear (baitboat, purse seiners and longliners).

The CPUE of small bigeye caught in surface fisheries shows large fluctuations, but without a clear trend (see Figure 13a). The CPUE of large bigeye, as indicated by the longline GLM abundance index (see Figure 13b), shows a moderate and regular decline since the beginning of the fisheries. These indices suggest that recruitment was stable and that the decrease in adult biomass was moderate.

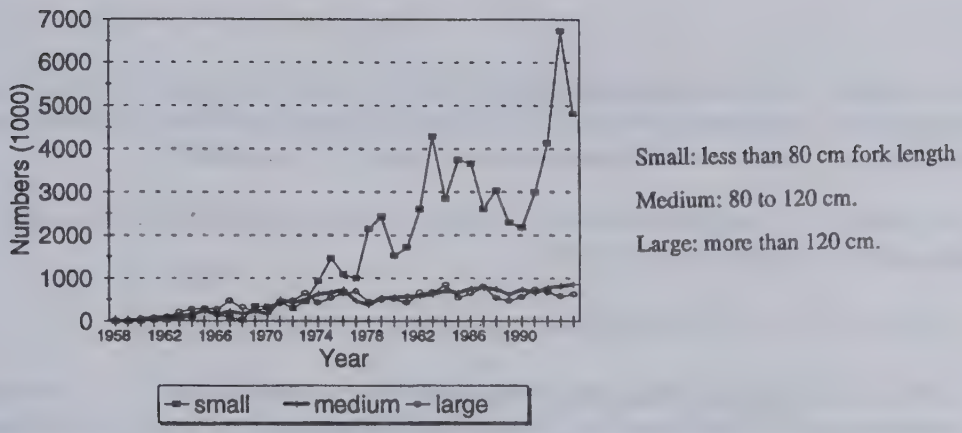


Figure 11. Catches of Atlantic bigeye tunas, by size category.

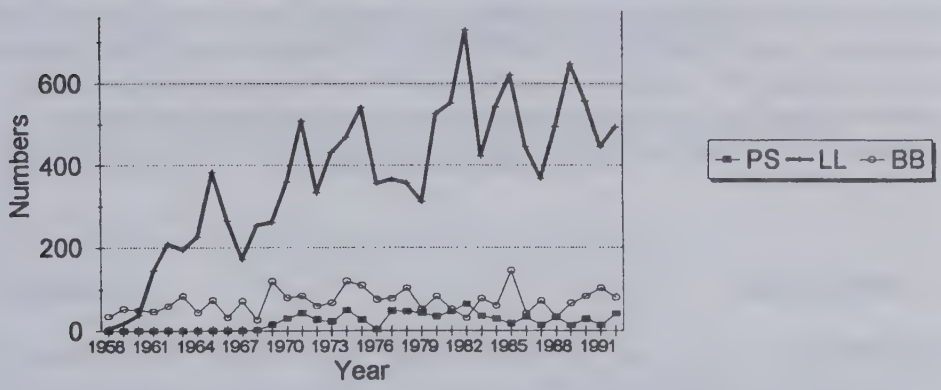


Figure 12. Catches of large (+1.2m.) Atlantic bigeye tuna by gear (BB=baitboat, PS=purse seine, LL=longline).

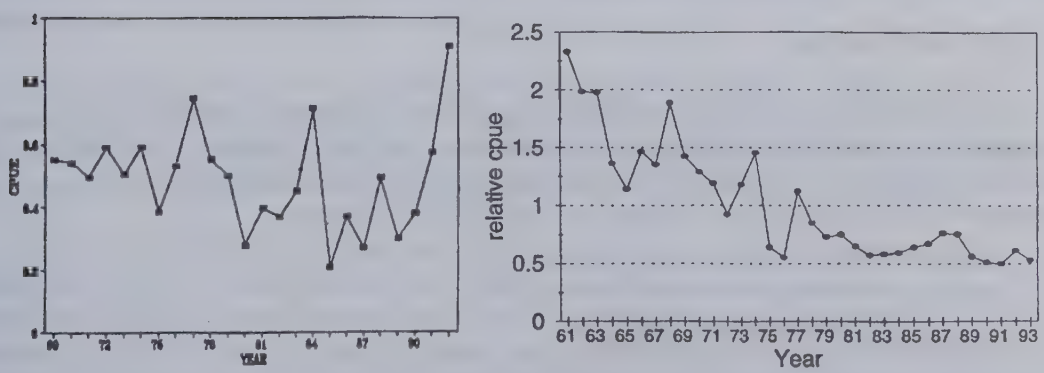


Figure 13. CPUE for bigeye tuna. (a, left) Surface fisheries--nominal CPUE of French purse seiners, and (b, right) longline fisheries--GLM indices from ICCAT, 1994b.

It is clear for bigeye that the adults caught by the purse seine fishery cannot have a significant effect on the longline fishery. This is due to the small purse seine catches of large bigeye (Figure 13) and to the differences in fishing areas of the two gears.

The present stock assessment analysis on bigeye concludes that the decline of the adult abundances can be explained by two factors:

- by the increased catch of the longliners, reducing directly the adult biomass;

- by the increased catches of juvenile; the large numbers of small bigeye ((3 to 5 millions of individuals yearly) taken by surface gears correspond to a moderate fishing mortality and has had only a moderate effect on adult stock size. This is shown by the results of the VPA, which give estimates of the recruitment in the stock and in the adult fishery. The bigeye recruitment seems to fluctuate without decreasing trend (Pereira, 1994). However, the decrease of this adult recruitment is clear, at a rate of approximately 20 % to 30 % between the "virgin" stock (e.g., the level of the stock during the early 1950s) and recent years, but is relatively moderate. It can be noticed also that present yield per recruit analysis indicates that the juvenile fishery affects the longline fishery, but does not significantly reduce the overall yields, at least at present levels of fishing mortalities (Pereira, 1994).

5.4 Yellowfin Tuna

5.4.1 Fisheries

The tuna fisheries in the Atlantic, caught an average of 154,000 mt of yellowfin per year during the period 1988-92 (Figure 2). The fisheries are located predominantly in the eastern Atlantic (123,000 mt, i.e., 80% of the total catch), but also significantly in the western Atlantic (31,000 mt, i.e., 20%). Three gears are primarily catching yellowfin in the Atlantic: purse seiners (73% of the catches), pole-and-line baitboats (13%) and longliners (5%).

5.4.2 Stock structure

The migrations of yellowfin tunas between the eastern and western Atlantic are now assumed to be significant, and a single-stock hypothesis has been accepted by the SCRS scientists since June 1993 (Figure 14). This conclusion was based on the transatlantic recoveries of tagged fishes and on the catch and CPUE of fisheries.

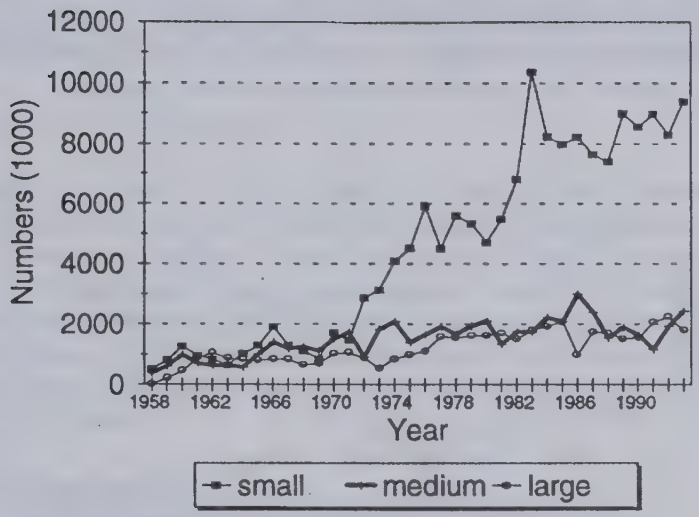


Figure 14. The hypothetical stock structure of Atlantic yellowfin presently accepted by the SCRS in 1993.

5.4.3 Interactions

The yellowfin stock has been heavily exploited since the early 1980s; the stock producing an average catch more or less equal to the estimated MSY of the stock. The fishing zones of small yellowfin are quite similar to the adults, at least for purse seiners; however, small yellowfin are usually caught in more coastal waters than the adults. The adults of yellowfin taken by longliners also show a wider area of distribution, scattered between 10°N (reaching 50° N in the western Atlantic), and 10°S from America to Africa. The adult yellowfin taken by the purse seiners are predominantly caught in a restricted and small area, in the major spawning area of the eastern Atlantic (Figure 14).

The numbers of small (-70 cm), medium and large (+120 cm) yellowfin taken by Atlantic fisheries are given in Figure 15. Figure 16 shows the dramatic increase of small yellowfin in the catches during recent years by purse seiners, and the relative stability of the large yellowfin catches since 1975 (decreased catches by longline and increased catches by purse seiners).

The catch and CPUE of small yellowfin, (taken by baitboats and purse seiners), showed some year to year variability, but no definite trend, suggesting a relatively stable recruitment. The abundance trend of large yellowfin measured by the CPUE on large yellowfin by longliners and purse seiners showed for recent years a moderate decline. However this decline is quite difficult to evaluate precisely for both longliners and purse seiners. The purse seiners in recent years have increased their fishing power due to changes in nets, the use of bird radar and other computerised facilities. The practical effect on the catch rates of those changes are difficult to evaluate precisely, but the recent abundances of yellowfin may be overestimated.

The change of target species from yellowfin to bigeye occurred in recent years with a shift in fishing zones and increased fishing depth of the longline (the densities of bigeye being higher at greater depths, densities of yellowfin being lower). Consequently, it is quite difficult to calculate a CPUE index for longliners that is representative of yellowfin abundance.

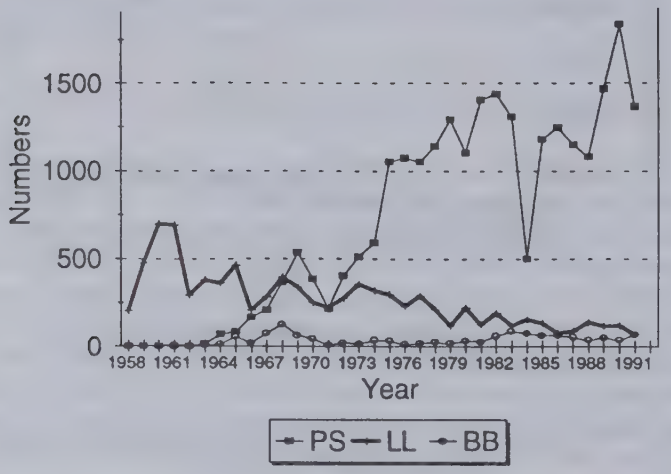


Figure 15. Catches of large (+120 cm) Atlantic yellowfin tunas by gear (BB=baitboat, PS=purse seine, LL=longline).

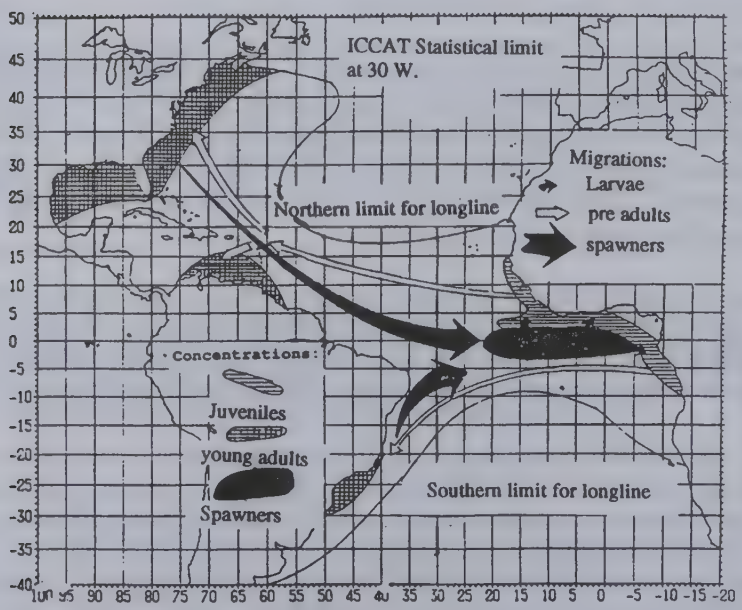


Figure 16. Catch of Atlantic yellowfin tunas, by size category.

The decline of the adult CPUE corresponds to a decline of the adult abundance. The interpretation of the VPA results (ICCAT, 1994b) can be that this decline of adult stock is a consequence of two factors: (a) the development of fisheries for juveniles which reduces the recruitment to the adult stock, and (b) the increased effort toward, and catches of, adults which directly reduces the adult biomass.

Present analysis suggests that the first effect--interaction between fisheries for juvenile and adult yellowfin--would be significant. This is shown by the decline of the adult recruitment estimated by VPA at approximately 50% between the early period of the fisheries and the present fisheries; the decline due to the increased catch of juveniles. However, subsequent yield per recruit analysis shows that the juvenile fishery does not seriously decrease the yield per recruit of the overall fishery because the juvenile catch is only slightly less (in weight) than the subsequent theoretical loss of the adult fisheries (at least with a high M estimated for the juveniles) (ICCAT, 1994b).

5.5 Bluefin Tuna

5.5.1 Fisheries and stocks

The bluefin fisheries in the Atlantic, caught an average of 26,800 mt per year during the average period 1988-92. The fisheries are located predominantly in the eastern Atlantic (6,400 mt) and Mediterranean Sea (17,400 mt), but also some bluefin are caught in the western Atlantic (3,000 mt). Various gears are used to catch bluefin tuna in the Atlantic, but purse seiners (45% of the catches) and longliners (17%) are the most important.

5.5.2 Stock structure

The migrations of bluefin tunas between the eastern and western Atlantic have been well shown by tagging and transatlantic recoveries. Nevertheless, until November 1993, a two stocks hypothesis assuming no significant east/west mixing and no potential interactions between the eastern and western Atlantic fisheries was assumed by the SCRS scientists. However, a mixing stock hypothesis seems now to be better accepted by various scientists, following the recommendations developed by experts from the USA (NRC group of experts) in 1994 (Figure 17). This stock structure hypothesis is clearly of key importance in the stock assessment and management of the Atlantic bluefin stock, even if the mixing rates between east and west bluefin populations are low (about 3% yearly?). The importance of the mixing and the potential interactions between stocks and fisheries located in both sides of the Atlantic are becoming major issues in the ICCAT stock assessment and management.

The condition of the bluefin stock in the western Atlantic appear to be consistently poor since the early 1980s, despite the establishment of small catch quotas in this area to increase population size. This stock has shown during recent years a critical decreasing trend of recruits and spawning biomass. On the contrary, the bluefin stock in the eastern Atlantic and the Mediterranean Sea seem to be in better condition; the recent increases in catches following the increasing effort have been sustained. Still this stock is showing a spectacular decrease of its spawning biomass, and its exploitation rate seems to be presently very high for most age groups. However, recruitment levels in the eastern Atlantic remain stable and high, being estimated at millions of fish yearly.

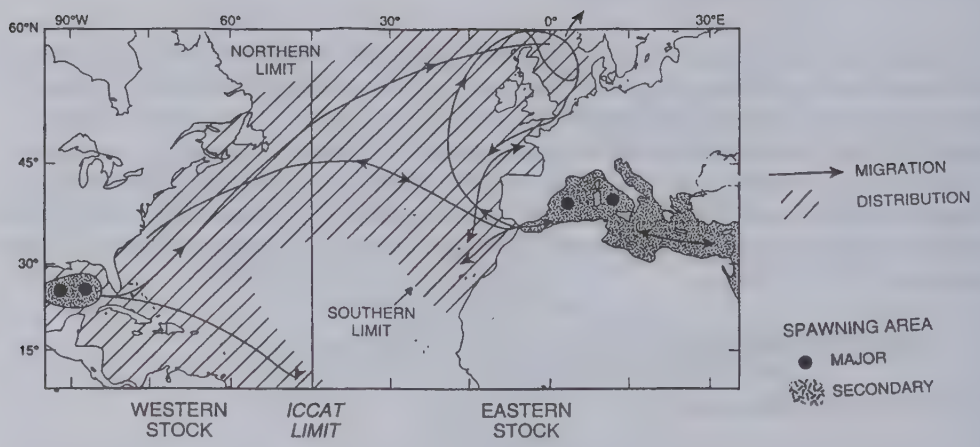


Figure 17. The hypothetical stock structure of Atlantic northern bluefin being discussed by the SCRS.

5.5.3. Interactions

The Atlantic bluefin tuna is a species with a large potential growth (the giant bluefin may exceed 500 kg) and low natural mortality (M estimated at 0.2, i.e., 18% of the population dying yearly of natural causes). A logical consequence is that there is a large potential of competition between the fisheries catching small bluefin and those catching large individual. This quite obvious yield per recruit competition was at the origin of the bluefin size limit of 6.4 kg imposed by ICCAT since 1975. The Atlantic bluefin may also offer various interesting other types of interactions between fisheries. During past years this species has shown that some local fisheries that have been active for years vanished suddenly without any clear scientific explanation; e.g., Norway, Morocco and Brazil provide good examples of collapsed fisheries. It is not clear if those negative changes were linked with an environmental variability or to a competition between fisheries. They may be due, for instance, to changes in the local environment (for instance waters getting too cold or to warm for the tunas), or to a decrease in food locally available to the tunas, e.g., the overexploitation of the local small pelagic resources may also explain why bluefin tunas disappeared from some areas. They also may be due to a possible heterogeneity of the stocks as explained earlier.

In the stock assessment conducted by ICCAT scientists until 1993, no potential interaction could exist between the eastern and western Atlantic fisheries since a two-stock hypothesis was assumed. In the "1994 mixing stock hypothesis" (proposed by the NRC experts and accepted by SCRS scientists), there is a potential interaction between the eastern and western

Atlantic bluefin stock and fisheries. Because a huge population is recruited in the eastern side and a very small one in the west, even a low mixing rate is sufficient to bring significant numbers of bluefin into western areas. Any error or inter-annual variability in this east-to-west mixing rate may change dramatically the absolute numbers of fishes in the western component (this variability is thought to be important based on bluefin tag recovery data). This problem is now being analysed by the SCRS scientists (primarily from tagging recovery data and modeling).

5.5.4 The standard "homogeneous" stock assessment

In the standard stock assessment, each stock is implicitly assumed to be a homogeneous unit; each individual fish shows the same behaviour as other fishes from the same cohort. So, in this case the stock (i.e., the management unit) corresponds to a single homogeneous population (genetic unit). Consequently, the decreasing biomass trends may often be reversed. If the stock recruitment relationship allows for a compensation, the stock will slowly return to its original levels under a reduced (or null) fishing mortality (stability of the MSY).

5.5.5 Bluefin tuna: a genetically heterogeneous stock?

The hypothesis of a genetic heterogeneity may well be accepted for bluefin tuna, because of the possible homing behaviour of the species and because of the long life expectation (each fish will spawn for about 10 to 15 years which allow some stability in time for such units). In this hypothesis, bluefin could be like salmon or marine turtles; thus, instead of having a single homogeneous population, there could be various self sustaining and independent genetic units or multiple sub-populations. Each unit would spawn in a precise time and area strata, and would conduct an exact migration pattern, characteristic of each genetic group; at the age of first spawning, this group of fishes would return to meet and spawn in a specific site and time with individuals belonging to the same genetic unit.

If this situation exists, genetic units may be extinguished. The loss of the genetic unit could result from repeated adverse environmental conditions in the migratory routes. Local and repeated overfishing in a specific point of the migratory route may also produce an extinction of this original genetic unit. The loss of the genetic unit could also result from environmental conditions becoming adverse in the geographically fixed spawning strata. This lack of flexibility in the choice of the spawning strata is probably a major biological necessity for all homing species. It may have strong evolutionary advantages in the long term, as shown by Cury (1994), but it may be fatal in the short run for a given genetic unit. In this case, the stock may never recover to its original levels, because of the loss of its genetic diversity. The MSY would then be decreased following the overexploitation or the changes in the environment (with a corresponding decrease of the optimal fishing effort).

If the absence of bluefin tuna presently observed in some of their traditional feeding grounds corresponds to this "cascading extinction of various sub-populations", various bluefin stocks may be following this scheme of heterogeneous genetic units. This loss of genetic diversity and of potential biomass of the stock may be irreversible in the short term. In the longer and evolutionary terms, the adaptive potential of migrating and spawning strays, would probably allow a stock recovery under a different biological and geographical pattern (for instance creating new spawning areas, other migratory routes and increased potential catches for fisheries). Such a case may have been developed in the Mediterranean Sea, when this sea

was colonised by spawning (and homing) bluefin tunas, which possibly strayed from the western Atlantic.

5.6 Albacore

5.6.1 Fisheries

The albacore fisheries in the Atlantic caught an average 63,000 tons per year during the average period 1988-92 (Figure 2). They were located predominantly in the North Atlantic (31,300 mt), South Atlantic (27,900 mt), and Mediterranean Sea (2,900 mt). This present level of catches is significantly lower than the 80,000 tons yearly catches observed until the 1960s and early 1970s. Three gears traditionally catch albacore: longline (50%), trolling and baitboat. However, during recent years a significant increase of the catches by new gears, midwater trawling and drift gillnets, were observed in the northeastern Atlantic (15% of the North Atlantic catches).

5.6.2 Stock structure

The hypothesis of three independent albacore stocks, in the North and South Atlantic and the Mediterranean Sea, has always been accepted by the SCRS. This hypothesis is well supported by the absence of north-to-south migration of tagged albacore and by the prevailing low densities of albacore in the inter-tropical Atlantic.

5.6.3 Interactions

The present status of albacore stock in the North Atlantic is being discussed by ICCAT scientists. This stock appears to be presently under-exploited (as indicated by both the global and analytical models), because of the decrease of fishing effort by surface and longline fisheries (for the obvious economic reasons of a lack of efficient fishing gear and the low value of the species in most tuna markets). The South Atlantic stock seems to be fully exploited, with longlines being the major gear exploiting this stock.

The problem of potential interactions in the North Atlantic albacore fisheries has not been examined in detail. However, various types of interactions can be shown for this stock, for instance:

- The yield per recruit interaction between the surface fisheries and the longline fisheries. The surface fisheries catch juvenile albacore (ages two to four), below the optimal size (in term of yield per recruit), thus reducing recruitment to the longline fishery (ICCAT, 1994).

- The local interactions between various surface gears operating in the Bay of Biscay; the fisheries include trollers, midwater trawlers, pole-and-line, baitboats and driftnets.

Those potential interactions are still under scrutiny by scientists. Basically they could belong to two categories:

- either a simple "urn competition", where the more efficient gear catches part of the local biomass before the other less efficient gear, thus reducing the CPUE,

- or possibly a decrease of the efficiency of the "traditional" gear due to the introduction of the new gear. In such an interaction, the fishes could for instance be frightened by the drift gillnet, or their movement patterns could be modified, the consequence being a lower catchability for the traditional gear (the total local biomass being unchanged). However, it was not possible until now to confirm this hypothesis by an *ad hoc* observers program.

5.7 Swordfish

5.7.1 Fisheries

The swordfish fisheries in the Atlantic Ocean have shown a spectacular increase in their activities in recent years, with the catches increasing from less than 12,000 tons per year during the 1960s and 1970s, to an average 44,000 tons during each of the last five years (Figure 2). The major gear catching swordfish was longline (78%). During the same recent period, the catch was geographically distributed as following: 35% in the North Atlantic, 30% in the South Atlantic and 35 % in the Mediterranean Sea.

5.7.2 Stock structure

The present SCRS analyses has worked under the hypothesis of three independent stocks of swordfish in three areas, with no potential interactions. This hypothesis was based on the analysis of fishery data and tag and recovery data. Unfortunately tag release and recovery rates are low for swordfish. In fact, the fishing zones of swordfish in the Atlantic show a north-south continuum of the high abundance and catches, which suggests that the 5° N limit used by ICCAT scientists may not be a real biological frontier between a northern and a southern so-called "stocks". This is unlike the clear case for albacore. This hypothetical stock structure is in fact highly problematic in the absence of strong scientific data to support it.

5.7.3 Interactions

The Atlantic swordfish is considered to be presently heavily exploited, at least in the North Atlantic. The yield per recruit analysis presently conducted on swordfish indicates clearly that there is a serious potential for competition between the fisheries targeting small individuals and the fisheries catching larger fish (at least presently under high exploitation rates). The ICCAT size limit adopted on North Atlantic swordfish since 1990 was based on this yield per recruit analysis.

The exact level of this yield per recruit competition is highly questionable and dependent upon a number of uncertainties, e.g., the recruitment trends and actual present exploitation rate of the stock(s). The present stock assessment of swordfish may provide a good example of the scientific errors done with VPA when the fishing patterns and exploited fishing zones are changing. Such changes, primarily the increasing size of the fishing zone, may have produced an increased recruitment which was not a biological reality (at the level of the true Atlantic swordfish population). It is also quite obvious that swordfish provide a good example of a tuna like species which is scattered ocean-wide (and in a wide range of depth, including very deep waters), when only the areas with the highest densities are exploited, and when only a fraction of the stock is presently exploited (as suggested by Figure 18). Consequently this species may still have a significant but unknown cryptic biomass in the Atlantic , thus the

present fishing mortalities, exploitation rates and potential interactions may have been overestimated. The present stability of the total swordfish catches in the North Atlantic since 1989, taken by a stable fishing effort (ICCAT, 1994a), may also be an indication that the swordfish global exploitation rate may have been overestimated by the SCRS (as the very high exploitation rate presently estimated should produced soon a decrease of the catches).

5.8 Other Billfishes

5.8.1 Fisheries

Various billfishes are exploited in the Atlantic Ocean. Most billfish are caught as a bycatch in industrial fisheries that target tunas. Three major species are taken in these fisheries: sailfish (2,100 mt annually), blue marlin (2,900 mt) and white marlin (1,300 mt). These fish are often discarded at sea and not recorded in the ICCAT statistics. Another significant part of the billfish catch is taken by the artisanal fisheries of Africa for local consumption and by sport fisheries, the major sport fisheries being located in the western Atlantic.

5.8.2 Stock structure

Very few studies are available on the stock structure of most billfishes. However, it is well shown by tagging that some species, e.g., blue marlin can undergo extensive trans-Atlantic migrations, thus allowing for a potential interaction between western and eastern Atlantic fisheries. A single Atlantic stock hypothesis was then used on this stock by the SCRS. Other species such as sailfishes show a limited potential for migrations (well shown by tagging and recoveries, that movement is always observed within a relatively short distance), and the stocks are probably limited to a regional scale. The stock assessment for sailfish is conducted under a two stocks hypothesis (eastern and western Atlantic).

5.8.3 Interactions

Very few studies of interactions between billfishes fisheries have been conducted, primarily because very few data were available. An interesting potential interaction case for billfishes is the local competition between commercial and recreational fisheries. Various countries, e.g., such as Venezuela and USA have developed policies giving priority to the development of sport fisheries. Governments have consequently put serious restriction to the access of EEZ waters where sport fisheries are active. The goal of those "intuitive" management measure was to reduce the local competition between sport and commercial fisheries, and to leave the entire local biomass available to the sport fishery ("urn" concept).

Unfortunately, no *ad hoc* scientific analyses were submitted to ICCAT, until now, to evaluate the practical effects of those regulations targeting on "local interactions". Such local interaction studies in which a competing fishery can be suppressed and the subsequent effects on the remaining fishery, would be of major interest to be studied in detail.

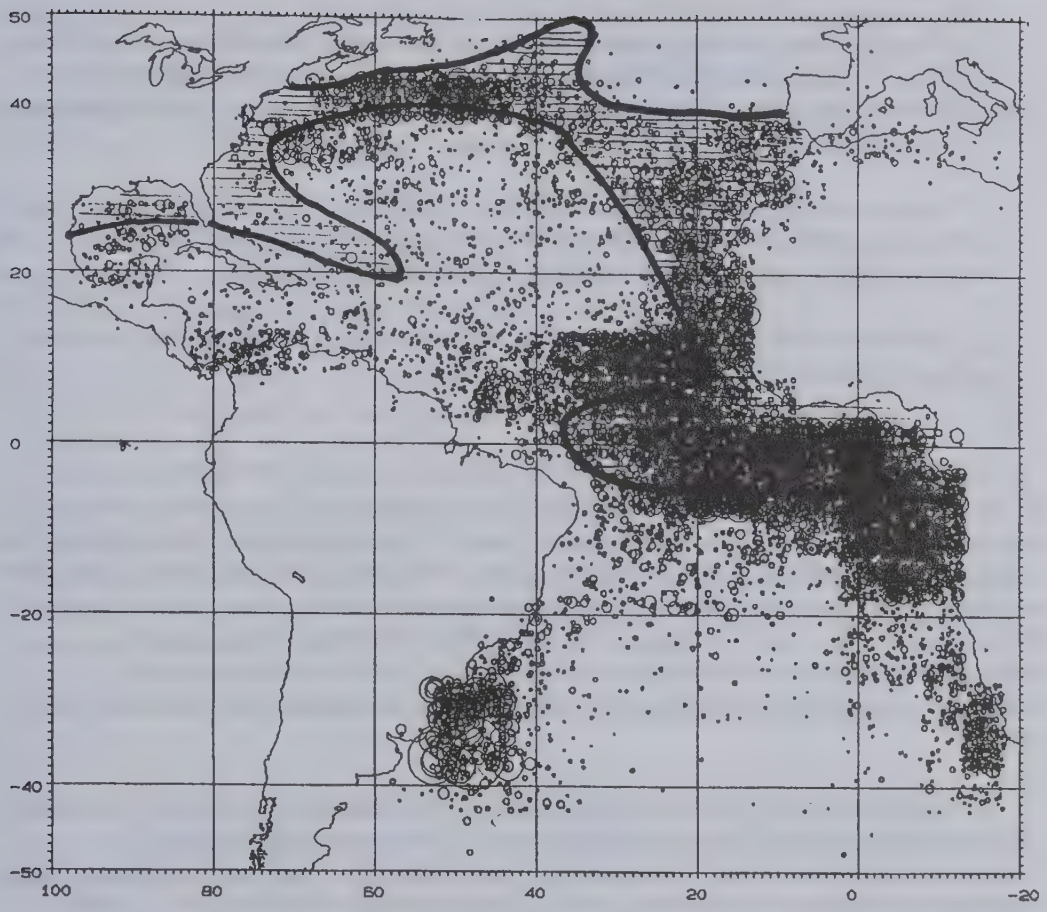


Figure 18. Areas of swordfish distribution in the Atlantic as shown by the monthly numbers of swordfishes caught (by 5 degree squares) by Japanese longliners between 1956 and 1993, compared to the present major fishing zones of fisheries targeting swordfish. The positions of catches are drawn randomly within each 5 degree square; only the monthly catches with more than 50 swordfish caught are represented. This figure indicates that swordfish are significantly present in a large area between 50°N and 40°S with very low or no fishing activities.

6. CONCLUSIONS

The analyses of interactions between tuna fisheries were developed explicitly during the early- and mid-1980s under the coordination of the FAO Fishery Department. These studies have been developed quite intensively during recent years especially in the western Pacific Ocean. This work has shown, as did similar studies conducted in other oceans, the real complexity of this problem, including the wide distribution of most tuna stocks (geographically and vertically), the complexity of their movement patterns (which are variable between species

and for each species between ages), and other multiple and heterogeneous factors which are often very difficult to integrate. Three types of research have been successfully developed in recent years:

1) A first progress has been obtained for various stocks with *the improvement of fishery statistics* (for instance better coverage of the statistics, better size composition of the catches and better species identification), allowing an improvement of the basic yield per recruit analysis.

2) The recent *tagging programs* successfully conducted on various stocks have provided more direct evidence concerning the tuna movements of various species(for instance in the western Pacific), a key element in the study for potential interactions.

3) The *integrated modeling of fishery data and tag-recovery data* has also shown very significant progress during recent years.

However, it would appear that a practical, comprehensive and definite answer to most of the interaction problems may be still pending, at least quantitatively. It is now presently impossible, in most cases and even when good data are available, to make realistic projections of the expected interactions between tuna fisheries. These difficulties are probably due to the extreme complexity and variability of the phenomena under study. In fact, the problem of interactions between tuna fisheries covers most of the uncertainties associated with comprehensive resource-wide stock assessments and small-scale stock assessments. Especially important are the uncertainties related to tuna movements, e.g., scale, type and intensity.

These studies need to cover the relationship between tunas and their environment, the behaviour and genetics of the tunas, their age specific changes of physiology and thermoregulation, their growth, the complexity and variability of their age specific movements patterns (from diffusion to advection), their age specific natural mortality, etc.. This list of important problems to consider in the analysis of potential interactions could cover most of the biological fields.

Further research, in both field of data collection and data analysis, are now necessary to evaluate better the real potential for interactions between various present or future tuna fisheries.

7. ACKNOWLEDGEMENTS

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INTERACTIONS AMONG FISHERIES IN SEPARATE GROUNDS: A TAG-RECAPTURE METHOD

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ABSTRACT

A tag-recapture experiment is suggested for determining the effect that a change in the fishing intensity of one fishery will have on its own catch and on the catch of another. The results are expressed as simple formulae in terms of one control variable: the proportional change in the fishing intensity of the altered fishery. There is no requirement to develop a complex parametric model of the dynamics of the population and fisheries or to collect comprehensive effort data. For the year-class being studied, the ideal experimental design requires that a representative sample of the fish caught by one fishery be tagged, and all tagged fish recaptured by the same fishery be re-released. In the second fishery (or fisheries), no fish need be tagged or re-released. Alternative equivalent procedures to re-releasing tagged fish are described. The dynamics of the fish population and fisheries are assumed to be independent of the size of the population, i.e., a linear dynamic system is postulated. The formulae are proven for two population models for which, (i) two fisheries catch fish from a common, homogeneously - mixed population, and (ii) two fisheries catch fish from separate grounds (fish may migrate between grounds). In some situations the formulae are size-based. Experimental design and formulae are developed to assess interactions when the fishing intensities of two or more fisheries are to be changed or a new fishery is proposed.

1. INTRODUCTION

Oceanic fish are mostly harvested as common resources. Many fish stocks are harvested by fisheries with different gear types, markets, seasons and fishing grounds. The degree to which the catch of one fishery decreases the catch of another at a later time is of concern to scientists, managers and fishers. With such knowledge, they may predict the effect that opening (or closing) a specific fishery may have on the catch of another fishery, which could assist managers prevent or resolve conflicts among fishers and optimise the exploitation of the resource.

The problem of fisheries interactions may be addressed in a number of ways (Kleiber, 1994). One approach is to develop parametric models of the dynamics of the fish population and associated fisheries. The parameter values are then estimated by fitting the model to detailed catch, effort and/or tag-recapture data (e.g., Sibert, 1984; Hilborn, 1990; Hampton,

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1 Some of this work formed part of the principal author's doctorate awarded by University of New South Wales.

2 Commonwealth Scientific and Industrial Research Organisation.

3 An earlier draft of this manuscript was prepared before Dr A. Mazanov's untimely death.

1991; Kleiber and Fonteneau , 1994; Salvado, 1994; Sibert and Fournier, 1994; Hampton et al, 1995; Mullen, 1995; Sibert et al., 1995).

Another approach is to study statistical correlations, between different fisheries, of time-series of fisheries statistics (e.g., Fonteneau, 1986; Suzuki, 1988; Bayliff, 1994; Medley, 1994). However, the correlations observed do not necessarily indicate a causal relationship, given the relatively short length of most fisheries catch-and-effort time-series.

Results from data analyses can also be incorporated into computer simulation models that estimate fisheries interactions under a variety of reasonable assumptions (e.g., Kleiber and Baker, 1987; Bertignac, 1995; Kleiber and Fonteneau, 1995). The range of possible results and interpretations of such an approach are often too wide, although the results are frequently useful for identifying the most critical areas for further study.

An experimental tagging approach developed by Majkowski et al. (1988) simulates the proposed change in one fishery by tagging and releasing fish in that fishery and estimating the effect on the catch of another from the biomass of the second fisheries recaptures. The basic concept behind this method is that each fish tagged in one fishery represents a fish which another fishery is potentially deprived of. If all fish caught by the first fishery are tagged, or the proportion tagged are known, one can determine the biomass of fish that the second fishery loses of due to the existence of the first fishery. This approach, unlike other methods, does not require the development of a population model, estimates of many highly correlated parameters, complex analyses or detailed catch-and-effort data; however, its experimental requirements are demanding. Whilst our method differs from these in many aspects we nevertheless follow their basic approach.

Majkowski et al. (1988) used catch quota as the control variable which, for their method, implicitly requires that the age distribution of the change in catch of one fishery be the same as its present catch — an impractical condition for most fisheries, unless a total closure is contemplated. In other words it is assumed that changing the catch of that fishery does not affect the age distribution of its catches (the zero catch excepted). To avoid this problem, we use effort as the control variable. As a consequence our corresponding formulae are different from theirs. They also assumed the population to be steady-state before the change and for there to be a transition period (sometimes substantial) before the population reaches a new steady-state — a very difficult condition to meet. We consider a particular year-class, so our approach is essentially a yield-per-recruit analysis, although we show how the formulae apply to the steady-state case.

The formulae of Majkowski et al. (1988) express only the change in one fishery in terms of the change in the other (which is unknown) and the tagging information. We also develop corresponding formulae for this, as well as those that express the change in catch of each fishery in terms of the present catch of one fishery and the tagging information.

The mathematical development of the method in Majkowski et al. (1988) assumes a homogeneously-mixed population, although they applied it to an example in which the two fisheries are spatially distinct. Fish migration and spatial differences between fisheries are important characteristics of many fisheries interactions – the analytic and experimental techniques for estimating them are still a matter of active research. We model the homogeneous case, as well as a more complex population structure in which two fisheries operate on separate fishing grounds. In the latter case tagging in one ground only is needed (unlike parametric models which require tagging in both grounds, as well as detailed catch and effort statistics).

The experimental design described in the present paper requires that a representative sample of fish harvested in one fishery is tagged and released. (Note most analyses of tagging experiments assume a representative sample of the population is tagged.)

The approach requires that some fishers re-release tagged fish they recapture. Compliance with this requirement is unlikely, but analytic methods and experimental approaches are proposed as alternatives.

2. THEORY

2.1 General Requirements

Consider two separate fisheries, X and Y, catching fish from the same or different fishing grounds. Management may be considering reducing (or increasing) the fishing intensity of X by a proportion ε and wish to assess the resultant change in Y's catch of a particular year-class. The fishing intensity of Y is assumed to remain unchanged. The more general objective is to estimate the effect on the catches of X and Y of changing the fishing intensities of both fisheries.

It is deemed that the following assumptions or conditions apply to the fishery, population and tagging experiment:

1. The rates of growth, natural and fishing mortalities, and migration are age-dependent and independent of population size.
2. Management can uniformly reduce the fishing intensity of fishery X by the desired proportion ε, while keeping the fishing intensity of Y unchanged.
3. The normal conditions of tagging experiments apply: that tagging does not harm fish or change their growth or behaviour; that tags are durable, are not shed from fish and are all reported by finders (or the level of tag loss and non-reporting can be estimated); and that enough fish are tagged to allow statistically-reliable results.
4. The age-distribution of the present catch of X is almost certainly required (see discussion on next condition). In some cases the total weight, or number, of fish caught by fishery X is needed.

Conditions 1 and 2 are implicit in most yield-per-recruit and interaction analyses. If the population and fisheries were significantly influenced by environmental fluctuations, then tagging programs would need to be conducted over a number of years to average over the range of normal variation.

The requirements of Condition 3 are difficult to meet, particularly that concerning the reporting of tags. The assumptions in tagging experiments and procedures for meeting them, or coping with non-compliance, are examined by Beverton and Holt (1957), Paulik (1961), Beverton and Bedford (1963), Hearn et al. (1991) and Pollock et al., 1994; 1995), and the literature on tuna and billfish tagging is reviewed by Bayliff and Holland (1986).

2.2 Experimental Design

The experimental method presented here is based on an idea originally proposed by Allen (1953) for estimating the optimum size-limit for a fishery by equating the marginal yield to zero. Knight (1970) extended it to estimate the optimum size of a fishing fleet. More recently, Majkowski et al. (1988) further developed this approach to estimate the effects of interactions among fisheries.

We design a tagging experiment to estimate ΔK_x and ΔK_y, the corresponding potential changes in the biomasses of catches (or yields) from a specified year-class by fisheries X and Y due to the proposed change in the fishing intensity of X. Under the existing fishing regime, the total number of fish caught by fishery X from the specified year-class is C_x, having a biomass of K_x, and a total biomass K_y of fish is caught by fishery Y. Apart from the need to comply with Condition 3, the experimental design requires two additional conditions:

5. Randomly tag N fish, having biomass Ω, of the selected year-class from the catch of fishery X. Tagging should be conducted over the entire period and geographical range that fish are susceptible to being caught by X, which may be for several years.

Sometimes it may be difficult to determine which year-class a fish belongs to, particularly if many year-classes are harvested by fishery X. As illustrated in Appendix C, mathematical adjustments would need to be made if the age distribution of fish tagged was different from those caught by fishery X. Condition (5), in effect, requires that the age (or length) distribution of the catch of X be estimated by some means, i.e., implies that the first part of Condition (4) be met.

6. Fishers in fishery X are required to re-release (unharmed) a proportion ε (the proposed proportional reduction in the fishing intensity of X) tagged fish they recapture (akin to the requirement of Majkowski et al. (1988) which requires that all fish recaptured by X be re-released) and report recapture weights (or lengths) to scientists. (This condition will be later modified.) Fishers in fishery Y are to retain all their recaptured fish and return tags with records of recapture weights (and/or lengths) to scientists.

Condition 6 is an experimental analogue of the thinning technique that is used in computer simulation studies, which generates a required mortality rate from another more-easily-generated mortality rate (see Lewis and Shedler, 1979; Devroye, 1986, p264). Therefore, the expected fishing intensity of X on tagged fish is reduced by a proportion ε from its level on untagged fish. Without Condition 6 only interactions, due to marginal changes of fishery X, can be estimated by this approach. The fishing intensity by Y on the tagged fish is assumed to remain unchanged.

If all vessels and their attributes are identical, then an equivalent requirement to Condition 6 is for a fraction ε of vessels belonging to X to re-release all recaptures, while fishery X's other vessels retain all theirs. The assumptions allow the tagged fish to represent the entire fish population, both in number and biomass, for which the change in fishing regime is proposed. The biomasses of tagged fish caught and retained by X and Y are R_x and R_y, respectively.

Given these conditions, we will prove the following relationships first obtained in Hearn (1986) for a homogeneously-mixed population:

$$\Delta K_y = \frac{\varepsilon C_x R_y}{N}$$

$$= \frac{\varepsilon K_x R_y}{\Omega}, \tag{1}$$

$$\Delta K_x = \varepsilon \frac{C_x R_x}{N} - \varepsilon K_x$$

$$= \varepsilon K_x \left[\frac{R_x}{\Omega} - 1 \right], \tag{2}$$

and

$$\Delta K_y = - \Delta K_x \frac{R_y}{\Omega - R_x} \tag{3a}$$

or

$$\frac{\Delta K_y}{\Delta K_x} = - \frac{R_y}{\Omega - R_x}. \tag{3b}$$

(The two forms of Equations (1) and (2) are equivalent because the expected values of K_x/Ω and C_x/N are equal, but the statistical properties, which are developed later, may be different.) Equation (3a) is obtained by the elimination of εK_x from Equations (1) and (2).

In Equations (1) and (2), ΔK_y and ΔK_x are expressed in terms of the control variable ε, the number (or biomass) of fish caught by X under the existing pattern of fishing, the number N (or biomass Ω) of fish tagged, and the corresponding biomasses of tagged fish recaptured by Y and X. In Equation (3a) ΔK_y is expressed in terms of biomasses R_x and R_y, the yield foregone by X ($-\Delta K_x$) and the biomass (Ω) of fish tagged.

In order to intuitively justify the validity of Equations (1) and (2), consider the effect of removing a proportion ε of vessels from fishery X. Let these vessels be fishery X_1 and the remainder of X be X_2. This is equivalent to a proportional reduction ε of fishing intensity if all vessels in fishery X are identical. We wish to assess the effects on the catches of X and Y of fishery X_1 ceasing to catch and retain fish.

In a hypothetical experiment, suppose that all fish of a selected year-class caught by X_1 are tagged and released, i.e., a number $N = \varepsilon C_x$ of fish with biomass biomass $\Omega = \varepsilon K_x$ are tagged. Also suppose that tagged fish recaptured by X_1 are all re-released. Consequently fishery X_1 does not retain any fish for sale and so the population of live fish, both tagged and untagged, become subject to fishing by fisheries X_2 and Y. Thus all the tagged fish are those that fishery X_1 would have caught and retained under the existing pattern of fishing, while the untagged fish would be the corresponding live population under the existing fishing regime. Hence, the tagged fish caught by Y represent the increase in the yield of Y, i.e., $\Delta K_y = R_y$. The increase in the yield of fishery X is equal to the biomass, R_x, of the tagged fish caught by X_2 less the biomass $\Omega = \varepsilon K_x$ foregone by X_1. So Equations (1) and (2) are intuitively justified.

In an actual tagging experiment a representative sample of fish caught by X would be tagged, and $\varepsilon C_x / N$ (or $\varepsilon K_x / \Omega$) is the factor needed to scale up the experiment to the size of the commercial catch. These arguments also apply if fishery X is defined to be that part of the fishing gear which catches fish less than a certain size, with fishery Y defined as the remaining part of the gear, i.e that which catches fish at or above that size. Therefore, questions regarding size limits can also be addressed by the application of Equations (1-3).

If both fishing and population are assumed steady-state (i.e., recruitment, the pattern and intensity of fishing, catches, fish growth and behaviour are consistent from year to year) an alternative approach is to tag a representative sample of fish from the catch of X during one year over all year-classes. Here K_x and K_y represent stabilized annual yields of fisheries X and Y, rather than lifetime yields of a cohort. However, once the fishing intensity of X is changed there will be a transition period (up to the life-span of the species) before the age structure of the population stabilizes again. The change in yield, ΔK_y, as derived from Equations (1) and (3a), is an estimate of the change in the annual yield of Y between one stable population and the next. An advantage of this method, together with the steady-state assumption, is that, although it is based on an underlying aged-structured model, it does not require the age of any fish to be known, i.e., it is a size-based method.

If the effect of a marginal change to fishery X were to be estimated, then ε would be close to zero, and so an approximate estimate of ΔK_y could be calculated from Equation (3a), with R_x and R_y being obtained from an experiment with no re-releasing. On the other hand, it may be planned to close fishery X altogether (i.e., $\varepsilon = 1$). In this case $R_x = 0$ because fishery X would retain no tagged fish. Consequently, Equation (3a) becomes

$$\Delta K_y = - \Delta K_x \frac{R_y}{\Omega}, \qquad (4)$$

which is Equation (1) of Majkowski et al. (1988); it clearly does not estimate marginal interactions, as claimed by Kleiber (1994).

Equations (1) and (2) can be combined to give the total change ΔK_T in the catch of both fisheries, viz.

$$\Delta K_T = \frac{\varepsilon K_x [R_y + R_x - \Omega]}{\Omega}. \tag{5}$$

The intuitive arguments to establish Equations (1) and (2) for general linear population systems were developed without constructing a mathematical population model. However, the structures of linear population systems can be quite complex and non-intuitive. Therefore, we also derive these equations for two different general fishery population models: (i) for a homogeneously-mixed population and (ii) for two fisheries harvesting in separate grounds, for which fish may migrate between grounds.

2.3 Population Model 1 - Homogeneously-Mixed Population

Consider two separate fisheries, X and Y, harvesting from a homogeneously-mixed population. The dynamics of the population of a particular year-class are assumed to be dependent only on age. The number of fish, $P(t)$, at age t can be described by

$$\frac{dP(t)}{dt} = - a(t)P(t), \tag{6}$$

where $a(t) = M(t) + F_x(t) + F_y(t)$, $M(t)$ is the natural mortality rate, $F_x(t)$ the fishing mortality rate of X, and $F_y(t)$ the fishing mortality rate of Y. $M(t)$ may incorporate an emigration component to allow for fish that permanently leave the fishing ground. From Equation (6) it can be shown that

$$P(t) = P_r \exp\{ - \int_r^t a(t')dt' \}, \tag{7}$$

where P_r fish are recruited to the ground at age r. (Recruitment may take place over a period of time, which could be incorporated into the model by recruiting $P_\rho \delta\rho$ fish between ages ρ and $\rho+\delta\rho$.) Equations (1) and (2) are derived from Equation (7) in Appendix A.

2.4 Population Model 2: Two Fisheries Harvesting in Separate Grounds

For convenience let the separate grounds that fisheries X and Y operate in be called grounds X and Y, respectively. The dynamics of a particular year-class of fish can be described by

$$\frac{dx(t)}{dt} = - a(t)x(t) + b(t)y(t) \tag{8}$$

and

$$\frac{dy(t)}{dt} = q(t)x(t) - s(t)y(t), \tag{9}$$

where $x(t)$and $y(t)$ are the numbers of fish in grounds X and Y, $a(t) = M_x(t) + F_x(t) + T_{x,y}(t)$, $b(t) = T_{y,x}(t)$, $q(t) = T_{x,y}(t)$, $s(t) = M_y(t) + F_y(t) + T_{y,x}(t)$, $F_x(t)$ and $F_y(t)$ are fishing mortality rates, $T_{x,y}(t)$ the rate of transfer (migration) from ground X to Y and $T_{y,x}(t)$ the reverse transfer rate. $M_x(t)$ and $M_y(t)$ are the natural mortality rates which may incorporate emigration components to allow for fish that permanently leave both grounds.

Note that Equations (8) and (9) have been used previously to describe the dynamics of fishing acting on separate grounds, e.g., Beverton and Holt (1957) and Sibert (1984). The latter estimated natural and fishing mortality rates and transfer rates by analysing data from tagging in two fishing grounds and corresponding catch and effort information, but the rates of

natural mortality and transfer were assumed constant. In the model represented by Equations (8) and (9), these rates are assumed to be dependent only on age, and for each ground the fish are assumed to be homogeneously mixed. Fish may be recruited to either or both fishing grounds, and r is the age that fish begin to be captured.

The solutions $x(t)$ and $y(t)$ of the differential Equations (8) and (9) have no general analytic expressions. However, if $b(t) = 0$ (i.e., fish migrate from X to Y, but not the reverse) analytic solutions can be obtained and the justification of Equations (1) and (2) follows a similar procedure to that given in Appendix A. If $b(t) \neq 0$ a different approach is required, which is presented in Appendix B.

3. MODIFICATIONS

3.1 Increasing the Fishing Intensity of X

The experimental Condition 6 is designed for estimating the effect on catches of a specific reduction in the fishing intensity. However, modifying it to require all tagged fish that are recaptured by X be re-released is more appropriate to general analyses. Importantly, the formulae obtained, when this condition is implemented, are applicable to assessing the effects of increasing the fishing intensity of fishery X.

If management plans a proportional reduction of ε (which would be negative if an increase were planned) in the fishing intensity of X, the estimates of R_x and R_y would be

$$R_x = \sum_{i=0}^{m} (1 - \varepsilon) R_{x,i} \varepsilon^i , \tag{10}$$

and

$$R_y = \sum_{i=0}^{m} R_{y,i} \varepsilon^i , \tag{11}$$

where $R_{x,i}$ ($R_{y,i}$) is the biomass of fish caught by X (Y) that have previously been re-released i times by X, and m is the maximum number of re-releases of any fish by X. It is noted that all recapture weights of a fish re-released several times would contribute to R_x.

The biomass of tagged fish recaptured for the first time by X is $R_{x,0}$. In the experiment that assesses the effects of reducing the fishing intensity of X, the fraction, $1 - \varepsilon$, of these fish would be retained by fishery X which is equivalent to adding $(1-\varepsilon) R_{x,0}$ to R_x as in Equation (10). Also a fraction ε of fish caught by X would be re-released, which is equivalent to re-releasing all fish recaptured by X and giving each a value of ε, which compounds each time the fish is re-released.

Clearly, Equations (10) and (11) have direct intuitive meanings only for $0 \leq \varepsilon \leq 1$. However, they do give correct estimates of R_x and R_y for negative values of ε, i.e., when it is proposed to increase the fishing intensity of X by a factor ε. To illustrate this, consider a proposal to double the fishing intensity of fishery X. Here $\varepsilon = -1$ and the interpretation of Equation (10) follows. A tagged fish recaptured by X for the first time has double its caught weight added to R_x (i.e., $1 - \varepsilon = 2$), once for itself and once for an equivalent tagged fish that would have been caught if the fishing intensity of X had been doubled. However, this equivalent fish is still in the water so it is compensated for by re-releasing the tagged fish to the

water with a value of minus one (i.e., $\varepsilon = -1$). This explains why some terms in the expressions for R_x and R_y in Equations (10) and (11) become negative for negative values of ε.

The implementation of the modified form of Condition 6 is preferred, as it allows a range of values of ε ($\varepsilon \leq 1$) to be analysed, rather than one. Information is also obtained from more fish, which would tend to reduce the variance of the estimate of R_x and R_y. Additionally, it has the distinct advantage of simplifying re-release instructions to fishers.

A significant and representative proportion β of fishers may reliably re-release tagged fish without harm and record their weights (or lengths), e.g., if independent observers are on board. In such a case instruct other fishers not to re-release fish and modify Equations (10) and (11) by replacing ε^i with $(\varepsilon/\beta)^i$, but leave unaltered the $(1-\varepsilon)$ term in Equation (10).

The effect on the catch of fishery Y of starting a fishery in ground X, where none existed before, can also be assessed using this approach. Fish, with the same age composition as that intended for the catch of X, should be tagged during the period of its projected fishing season. Because no fish are presently being caught in ground X, then $R_x = 0$ and there can also be no re-releasing, so the effects of fishing in ground X cannot be correctly estimated from Equations (10) and (11). Nevertheless, if moderate yields from X are planned, a linear extrapolation of Equation (3a), with $R_x = 0$, would be approximately correct, i.e., Equation (4).

3.2 Changing the Fishing Intensity of Both Fisheries

Using simple interaction models, Beverton and Holt (1957) show that, for an over-harvested fish stock, a unilateral reduction of the fishing intensity of X always increases the catch of Y, but increases the catch of X only if its stock is over-harvested on a yield-per-recruit basis. To achieve an equitable share of the benefits of a reduction in fishing intensity, fisheries managers need to know the likely effects of changing the fishing intensity of both fisheries.

To achieve this objective, we suggest modifying Condition 5 by requiring that a random selection of fish caught by Y also be tagged. Like Condition 6, it is further required that a proportion γ of all tagged fish recaptured by Y be re-released, including those tagged in ground X. Similarly a proportion ε of all tagged fish recaptured by X should be re-released. The estimates of the changes in the catch of Y and X are:

$$\Delta K_y = \frac{\varepsilon K_x R_{x,y}}{\Omega_x} + \gamma K_y \left[\frac{R_{y,y}}{\Omega_y} - 1 \right] \tag{12}$$

and

$$\Delta K_x = \frac{\gamma K_y R_{y,x}}{\Omega_y} + \varepsilon K_x \left[\frac{R_{x,x}}{\Omega_x} - 1 \right], \tag{13}$$

where $R_{x,y}$ and $R_{y,y}$ are the biomass of fish recaptured by Y which were tagged in grounds X and Y, respectively, and conversely for $R_{y,x}$ and $R_{x,x}$. In practice one would require all fishers to return tags from all tagged fish they recapture and then calculate $R_{x,y}$, $R_{y,y}$, $R_{y,x}$ and $R_{x,x}$ by formulae similar to Equations (10) and (11).

Note that Equations (12) and (13) can be extended to estimating interactions among many fisheries. To achieve this objective, a random selection of fish caught by each fishery, having biomass Ω_m ($m = 1,2 \ldots n$), is tagged. It is required that a proportion ε_m of all tagged fish

recaptured by fishery m be re-released, including those tagged in other grounds. The estimate of the change in the biomass, ΔK_j, of the catch of fishery j is.

$$\Delta K_j = \sum_{m=1}^{n} \frac{\varepsilon_m K_m R_{m,j}}{\Omega_m} - \varepsilon_j K_j \ , \qquad (14)$$

where $R_{m,j}$ is the biomass of fish recaptured by fishery j that were tagged in ground m and K_j is the biomass of fish that were commercially caught by fishery j. Equations (12), (13) and (14) could be established in a similar way to Equations (1) and (2).

3.3 Substitutes for Fish that cannot be Re-released

In very few fisheries would fishers be expected to reliably re-release tagged fish without harm. Majkowski et al. (1988) proposed two methods for accounting for fish recaptured by fishery X that were not re-released. One has subsequently been found to be invalid[4]. However, their other proposal to tag and release equivalent fish for each one that is not re-released is a viable solution. This would require a low-level tagging program during the period when tagged fish are liable to be caught by X.

If one can not implement a substitute tagging program, the experiment can be simply conducted without requiring re-releases and then equivalent tagged fish can be randomly chosen to serve as the substitutes. If one of the "pseudo" substitute fish is recaptured it would be counted twice, once as a fish recaptured for the first time and again as a substitute for another fish. A variation of this technique is illustrated in Appendix C for a special case.

Or it can be assumed that the population is stable and a random sample of the catch of X over all ages is tagged during one season. An approximation to re-releasing may be to let the substitute fish be one that was tagged at about the recapture size (but not necessarily at the same time) as the fish that was not re-released. This requires the assumption that temporal differences are not important.

For an homogeneously-mixed population it is readily shown from Equation (7) that for fish tagged at age τ the proportion recaptured later by Y between ages t and $t + \delta t$ ($\tau \leq t$) is:

$$F_y(t)\exp\{-\int_{\tau}^{t} a(t')dt'\}\delta t,$$

if there is no re-releasing. Comparing this equation with Equation (A8), which incorporates re-releasing, it can be seen that for every tagged fish recaptured by Y when there is no re-releasing there would be

$$\exp\{\varepsilon \int_{\tau}^{t} F_x(t')dt'\}$$

recaptured if the required fish were re-released (note that $\alpha(t) = a(t) - \varepsilon F_x(t)$, see Equation (A4)). Given a value of the natural mortality, one could approximately estimate $F_x(t)$ by cohort analysis of the tagging data (see Bayliff, 1971). Alternatively, if the effort data of fishery X and an estimate of the catchability coefficient are available, one can estimate R_y without re-releasing tagged fish. A similar procedure would be applied if an estimate of R_x was required, but it would need to be multiplied by $1 - \varepsilon$ to allow for fish not retained by X. For fisheries in two grounds, these adjustments would be valid only while fish were in ground X (i.e., for

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[4] The method discounted recaptures by fishery X from the number (or biomass) of fish released. While this method allowed for natural mortality, the spatial structure of the population was not taken into account.

some unknown period smaller than $t-\tau$); therefore the values of R_y and R_x obtained in this way would be overestimated.

3.4 Estimating Standard Errors

If ΔK_y is estimated from the first form of Equation (1) then, using the delta method (see Seber, 1973, equation 1.11 p9) with C_x and R_y independent and assuming the term involving $Var(C_x)Var(R_y)$ is negligible,

$$Var(\Delta K_y) \approx \left(\frac{\varepsilon}{N}\right)^2 \left[Var(C_x)(R_y)^2 + (C_x)^2 Var(R_y)\right], \tag{15}$$

where $Var(C_x)$ could be estimated from the catch sampling statistics (catch samples are often large and comprehensive, in such cases $Var(C_x)$ may be negligible) and $Var(R_x)$ may be estimated from the independent tag-recapture data by Equation (C6) of Majkowski et al. (1984).

However, if ΔK_y is estimated from the second part of Equation (1), then similarly

$$Var(\Delta K_y) \approx \varepsilon^2 \left[Var(K_x)\left(\frac{R_y}{\Omega}\right)^2 + (K_x)^2 Var\left(\frac{R_y}{\Omega}\right)\right], \tag{16}$$

where $Var(K_x)$ could be estimated from the catch-sampling statistics and $Var(R_y/\Omega)$ from the tag-recapture data by Equation (B9) of Majkowski et al. (1988). In the development of the two previous equations it is assumed that a random sample of fish caught by fishery X are tagged, i.e., independence between fish is assumed. Independence does not apply when all fish recaptured by X are re-released and R_y is estimated from Equation (11). This is because some fish contribute multiple weights.

Adjustments would need to be made to the variance formulae in Majkowski et al. (1988) for them to be suitable for Equations (2), (3a), (5), (12), and (13). The procedures used to adjust results when assumptions are not complied with may be too complex for an analytic expression of variance. In such a case either of the jackknife or bootstrap methods could be used, as all the expressions are algebraic.

If fish form large schools, a tagging vessel would tag fish from some of the schools that would be subject to fishing by X. As the integrity of schools may persist for some time, the assumption of independence between fish may not hold. In such a case a bootstrap approach with schools as the basic unit may be preferable.

4. DISCUSSIONS AND CONCLUSIONS

We have demonstrated that Equations (1) and (2) generally hold for both increasing and decreasing effort. Therefore, tagging the catch from one ground (X) is sufficient if assessment of the effects of changing the fishing intensity of X is the only knowledge required. (Methods that derive, with good precision, a full solution of the dynamics of the population require that fish also be tagged in Y, e.g Bertignac, 1995.) Additionally, our formulae require estimates of the number (C_x) or biomass (K_x) of fish caught by fishery X and its age composition, but do not need detailed effort statistics. Tagging in ground X and not in Y would make more resources available to tag substitute fish or put independent observers aboard vessels in ground X to re-release fish. However, if a number of management options were being considered the experimental design would need to allow for all cases, which could be more expensive (e.g., tagging in both grounds).

The estimate of $\frac{\Delta K_y}{\Delta K_x}$ in Equation (3b) requires only tagging data and the age distribution of the catch, (i.e., it does not need estimates of C_x or K_x), and is less sensitive to ε than the Equation (1) estimate, which could be important if ε is not proportional to the measured change in effort (i.e., Condition 2 not met). Moreover, it does not require management to be committed to forecasting the absolute value of the change in catch of Y, which may be critical if recruitment is variable. It also addresses the question of what is the catch weight gained by fishery Y per unit of weight foregone by fishery X, which is particularly relevant when there is no existing fishery in ground X (in which case Equations (1) and (2) cannot be applied).

If the fish caught by X are young the length-frequency modes may be distinct, thus allowing reliable year-class identification. If so Equation (3b) essentially becomes a size-based formula. Also tagging in ground X is likely to be completed in only two or three years, thus increasing the feasibility of this approach. Moreover, if the average size of fish caught by Y is much larger than those caught by X there exists a potential for a strong fishery interaction, i.e $\frac{\Delta K_y}{\Delta K_x}$ may be substantial, which will be of concern to fishers operating in fishery Y and to managers. Additionally, the natural mortality and migration rates of young fish may vary markedly as they grow older: our approach deals with this aspect. We thus have a situation where a fishery interaction may be substantial, for which this method is likely to be particularly appropriate.

Experimental design and formulae, which are analogues of Equations (1) and (2), were developed for assessing interactions where the fishing intensity of two (or more) fisheries may be changed. This requires tagging in two grounds and catch information from each. The results generated from this procedure are expressed in terms of two (or more) control variables, which allows managers to allocate a more equitable share between fisheries of the benefit or loss that flows from the changes. Unfortunately, there is no analogue of Equations (3a) for this experimental design.

One difficulty with our approach is that a change in effort is not likely to be uniform over time and space (Condition 2). For example, an area may not be fished at all or the fishing season may be shortened. If one could predict how the reduction in effort was going to be distributed, then the fishery could be considered as a number of sub-fisheries. The experiment would be designed accordingly and Equation (14) used for analyses.

In Equation (11) $R_{y,0}$ would be the dominant term in R_y unless the catch of X is very high. This dominant term is not affected by non-re-releasing and/or non-reporting by fishery X. If a reduction in the fishing intensity of X is proposed, then $R_{y,0}$ is a lower bound for R_y, and hence a lower bound for ΔK_y can be estimated from Equation (1). Similarly, $R_{x,0}$ is a lower bound for R_x, and so a lower bound for the ratio $-\frac{\Delta K_y}{\Delta K_x}$ can be obtained from Equation (3b).

The use of Equations (8) and (9) with general age-dependent coefficients allows Equations (1) and (2) to be established for a simple spatial population model, a considerable advance over Majkowski et al. (1988), who established their formulae only for homogeneous populations. One may wish to construct more elaborate population models that incorporate spatially-varying advection and diffusion as, for example, those of Sibert and Fournier (1994). In such a case the proof of Equations (1) and (2) could be established in a similar way to that in Appendix B, by examining the differential properties of an analogue of Equations (B11) and (B12).

An important element of this experimental design — re-releasing a certain proportion of fish — is difficult to implement, but alternative strategies are to, re-release all fish, tag substitute fish, make mathematical adjustments, or use effort data in some cases. The value of placing

independent observers on fishing vessels is not only to ensure the re-release of tagged fish but also to allow assessments of the catch and/or tag non-reporting, which are difficult problems to address by other means.

Equations (1 - 3) essentially represents a Petersen approach (see Ricker, 1975, p77). The essential concept is intuitively simple, even if difficult to establish for a complex population model. Even so, a number of assumptions need to be met, particularly those relating to the tagging experiment. Other tagging approaches must also meet the normal tagging assumptions (Condition 3), but tagging a representative sample of the catch of X (Condition 5) and re-releasing recaptured fish (Conditions 6) are requirements specific to this method. An advantage of the approach is that it avoids the need to derive the age-varying coefficients implicit in Equations (6), (8) and (9).

The sum of ΔK_y and ΔK_x (= ΔK_T) from Equations (12) and (13) gives the total change in yield in terms of the change of fishing intensities ε and γ in fisheries X and Y. This allows curves of equal value of ΔK_T to be plotted against ε and γ for the information of managers. The application of Equation (14) would extend this approach to evaluate the effects of changing the fishing intensities of several fisheries.

The estimates of fisheries interaction obtained from such experiments could make a valuable contribution to helping managers evaluate proposed changes in the fishing intensity of different fishery components.

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APPENDIX A
HOMOGENEOUSLY MIXED POPULATION: PROOF OF EQUATIONS (1) AND (2)

The rate that fishery X catches fish is $F_x(t)P(t)$, so from Equation (7) the number (C_x) and biomass (K_x) of fish caught by X from the selected year-class are, respectively,

$$C_x = P_r \int_r^\infty F_x(t) \exp\{-\int_r^t a(t')dt'\}dt \tag{A1}$$

and

$$K_x = P_r \int_r^\infty W(t) F_x(t) \exp\{-\int_r^t a(t')dt'\}dt , \tag{A2}$$

where $W(t)$ is the weight of a fish at age t. The rate of catching fish by Y is $F_y(t)P(t)$, so the biomass of fish caught by Y is:

$$K_y = P_r \int_r^\infty W(t) F_y(t) \exp\{-\int_r^t a(t')dt'\}dt . \tag{A3}$$

From Equation (7) the population number $P^*(t)$ when the fishing intensity of fishery X is reduced by a proportion ε is

$$P^*(t) = P_r \exp\{-\int_r^t \alpha(t')dt'\}, \tag{A4}$$

where $\alpha(t) = M(t) + (1 - \varepsilon)F_x(t) + F_y(t) = a(t) - \varepsilon F_x(t)$.

If the changed regime, with its associated fish population represented by Equation (A4), operated for the entire lifetime of the selected year-class, the biomasses, K^*_x and K^*_y, of fish caught by fisheries X and Y would be

$$K^*_x = P_r \int_r^\infty W(t)(1 - \varepsilon) F_x(t) \exp\{-\int_r^t \alpha(t')dt'\}dt$$

and

$$K^*_y = P_r \int_r^\infty W(t) F_y(t) \exp\{-\int_r^t \alpha(t')dt'\}dt .$$

Therefore the changes in the yields of X ($\Delta K_y = K^*_x - K_x$) and Y ($\Delta K_y = K^*_y - K_y$) would be

$$\Delta K_x = P_r \int_r^\infty W(t) F_x(t) \left[(1 - \varepsilon)\exp\{-\int_r^t \alpha(t')dt'\} - \exp\{-\int_r^t a(t')dt'\}\right]dt \tag{A5}$$

and

$$\Delta K_y = P_r \int_r^\infty W(t) F_y(t) \left[\exp\{-\int_r^t \alpha(t')dt'\} - \exp\{-\int_r^t a(t')dt'\}\right]dt \tag{A6}$$

As a total of N fish are randomly selected from the existing catch of X and tagged, there are expected to be

$$\frac{NF_x(\tau)\exp\{-\int_r^{\tau} a(t')dt'\}}{\int_r^{\infty} F_x(\tau')\exp\{-\int_r^{\tau'} a(t')dt'\}d\tau'}\delta\tau \qquad \text{(A7)}$$

fish tagged between ages τ and $\tau + \delta\tau$. Of the tagged fish that are recaptured by X, a proportion ε are randomly chosen and returned unharmed to the water. According to the thinning technique (Lewis and Shedler, 1979; Devroye, 1986), the rate of fishing mortality acting on the tagged population of X would be $(1-\varepsilon)F_x(t)$.

Derivation of Equation (1)

By replacing τ for r in Equation (A4) it can be seen that, of fish tagged from the catch of X at age τ, the proportion recaptured later by Y between ages t and $t + \delta t$ $(\tau \le t)$ is expected to be

$$F_y(t)\exp\{-\int_{\tau}^{t} \alpha(t')dt'\}\delta t. \qquad \text{(A8)}$$

The expected total biomass R_y of tagged fish caught by Y is the product of Equations (A7), (A8) and $W(t)$ integrated over t and τ, viz,

$$R_y = \frac{N\int_r^{\infty} F_x(\tau)\exp\{-\int_r^{\tau} a(t')dt'\}\int_{\tau}^{\infty} W(t)F_y(t)\exp\{-\int_{\tau}^{t}\alpha(t')dt'\}dtd\tau}{\int_r^{\infty} F_x(\tau')\exp\{-\int_r^{\tau'} a(t')dt'\}d\tau'}. \qquad \text{(A9)}$$

Interchanging the order of integration in Equation (A9) with respect to t and τ and simplifying, the RHS of the first part of Equation (1) becomes

$$\begin{aligned}\frac{\varepsilon C_x R_y}{N} &= \varepsilon P_r \int_r^{\infty} W(t)F_y(t)\int_r^{t} F_x(\tau)\exp\{-\int_r^{\tau} a(t')dt'\}\exp\{-\int_{\tau}^{t}\alpha(t')dt'\}d\tau dt \\ &= \varepsilon P_r \int_r^{\infty} W(t)F_y(t)\exp\{-\int_r^{t}\alpha(t')dt'\}\int_r^{t} F_x(\tau)\exp\{-\varepsilon\int_r^{\tau} F_x(t')dt'\}d\tau dt\,. \end{aligned} \qquad \text{(A10)}$$

Using the identity

$$\varepsilon\int_r^{t} F_x(\tau)\exp\{-\varepsilon\int_r^{\tau} F_x(t')dt'\}d\tau = 1-\exp\{-\varepsilon\int_r^{t} F_x(t')dt'\}, \qquad \text{(A11)}$$

the RHS of Equation (A10) simplifies to the RHS of Equation (A6), thus establishing Equation (1).

Derivation of Equation (2)

Of fish tagged from X at age τ the proportion recaptured later by X between ages t and $t + \delta t$ $(\tau \le t)$ and retained is expected to be

$$(1-\varepsilon)F_x(t)\exp\{-\int_{\tau}^{t}\alpha(t')dt'\}\delta t. \qquad \text{(A12)}$$

The expected biomass R_x of tagged fish caught and retained by X is the product of Equations (A7), (A12) and $W(t)$ integrated over t and t, viz,

$$R_x = \frac{N \int_r^\infty F_x(\tau)\exp\{-\int_r^\tau a(t')dt'\}\int_\tau^\infty W(t)(1-\varepsilon)F_x(t)\exp\{-\int_\tau^t \alpha(t')dt'\}dtd\tau}{\int_r^\infty F_x(\tau')\exp\{-\int_r^{\tau'} a(t')dt'\}d\tau'} . \tag{A13}$$

Interchanging the order of integration in Equation (A13) with respect to t and τ and simplifying, the first term in the RHS of Equation (2) becomes

$$\begin{aligned} &\varepsilon \frac{C_x R_x}{N} \\ &= \varepsilon P_r \int_r^\infty W(t)F_x(t)(1-\varepsilon)\int_r^t F_x(\tau)\exp\{-\int_r^\tau a(t')dt'\}\exp\{-\int_\tau^t \alpha(t')dt'\}d\tau dt \\ &= \varepsilon P_r \int_r^\infty W(t)F_x(t)(1-\varepsilon)\exp\{-\int_r^t \alpha(t')dt'\}\int_r^t F_x(\tau)\exp\{-\varepsilon\int_r^\tau F_x(t')dt'\}d\tau dt \end{aligned} \tag{A14}$$

Using the identity Equation (A11) the RHS of Equation (A14) simplifies to

$$= P_r \int_r^\infty W(t)F_x(t)\left[(1-\varepsilon)\exp\{-\int_r^t \alpha(t')dt'\} - (1-\varepsilon)\exp\{-\int_r^t a(t')dt'\}\right]dt ,$$

which from Equations (A2) and (A5)
$= \Delta K_x + \varepsilon K_x$, thus establishing Equation (2).

APPENDIX B

TWO FISHING GROUNDS: PROOF OF EQUATIONS (1) AND (2)

At age t the rate that X catches fish is $F_x(t)x(t)$ and hence the total number, C_x, and biomass, K_x, of fish caught by X from the selected year-class are

$$C_x = \int_r^\infty F_x(t)x(t)dt \tag{B1}$$

and

$$K_x = \int_r^\infty W(t)F_x(t)x(t)dt , \tag{B2}$$

and similarly the biomass of fish caught by Y is

$$K_y = \int_r^\infty W(t)F_y(t)y(t)dt . \tag{B3}$$

If the fishing intensity of X is reduced by proportion ε, let the corresponding population numbers in grounds X and Y be $x^*(t)$ and $y^*(t)$. The differential equations describing these numbers are then

$$\frac{dx^*(t)}{dt} = -\alpha(t)x^*(t) + b(t)y^*(t) \tag{B4}$$

and

$$\frac{dy^*(t)}{dt} = q(t)x^*(t) - s(t)\,y^*(t), \tag{B5}$$

where $\alpha(t) = M_x(t)+(1-\varepsilon)F_x(t)+T_{x,y}(t) = a(t)-\varepsilon F_x(t)$.

Under the proposed new fishing regime, the corresponding biomasses caught by fisheries X and Y on their respective grounds are, similarly to Equations (B2) and (B3), expected to be

$$K_x^* = \int_r^\infty W(t)(1-\varepsilon)F_x(t)\,x^*(t)\,dt, \tag{B6}$$

and

$$K_y^* = \int_r^\infty W(t)F_y(t)\,y^*(t)\,dt. \tag{B7}$$

Therefore, the expected changes in the catches of X and Y are

$$\Delta K_x = \int_r^\infty W(t)F_x(t)[(1-\varepsilon)x^*(t) - x(t)]dt, \tag{B8}$$

and

$$\Delta K_y = \int_r^\infty W(t)F_y(t)[\,y^*(t) - y(t)]dt. \tag{B9}$$

As a total of N fish are randomly selected from the existing catch of X and tagged, there are expected to be

$$\frac{NF_x(\tau)x(\tau)}{\int_r^\infty F_x(\tau')x(\tau')d\tau'}\delta\tau \tag{B10}$$

fish tagged between ages τ and $\tau+\delta\tau$. Of the tagged fish that are recaptured by X, a proportion ε are randomly chosen and returned unharmed to the water.

Simplification of Proofs

If one fish is tagged in X at age τ and subject to the proposed fishing regime, then the probability of its being in X at age t is defined as $\tilde{x}^*(\tau, t)$ and in Y as $\tilde{y}^*(\tau, t)$ (i.e., Green's functions). We aim to show that it is sufficient to prove

$$y^*(t) - y(t) = \varepsilon \int_r^t F_x(\tau)x(\tau)\ \tilde{y}^*(\tau, t)\,d\tau \tag{B11}$$

and

$$x^*(t) - x(t) = \varepsilon \int_r^t F_x(\tau)\,x(\tau)\,\tilde{x}^*(\tau, t)\,d\tau \tag{B12}$$

to establish the corresponding Equations (1) and (2) for this population model.

Of fish tagged in X at age τ, the proportion recaptured later by Y between ages t and $t+\delta t$ ($\tau \le t$) is expected to be

$$F_y(t)\,\tilde{y}^*(\tau, t)\delta t. \tag{B13}$$

The expected total biomass R_y of tagged fish caught by Y is the product of Equations (B10), (B13) and $W(t)$ integrated over t and τ, viz,

$$R_y = \frac{N \int_r^\infty F_x(\tau) x(\tau) \int_\tau^\infty W(t) F_y(t)\ \tilde{y}^*(\tau, t)\, dt\, d\tau}{\int_r^\infty F_x(\tau') x(\tau') d\tau'}. \tag{B14}$$

By interchanging the order of integration in Equation (B14) with respect to t and τ and substituting for C_x from (B1), the RHS of Equation (1) becomes

$$\frac{\varepsilon C_x R_y}{N} = \varepsilon \int_r^\infty W(t) F_y(t) \int_r^t F_x(\tau) x(\tau)\ \tilde{y}^*(\tau, t)\, d\tau dt. \tag{B15}$$

By equating the RHSs of Equations (B9) and (B15) it is seen that it is sufficient to prove Equation (B11) to establish Equation (1).

Of the fish tagged in ground X at age τ, the proportion expected to be caught and retained by fishery X between ages t and $t+\delta t$ $(\tau < t)$ is

$$(1 - \varepsilon) F_x(t)\ \tilde{x}^*(\tau, t) \delta t \tag{B16}$$

The biomass, Rx, of all tags caught and retained by X is calculated by multiplying (B10), (B16) and W(t) and integrating over τ and t to obtain

$$R_x = \frac{N \int_r^\infty F_x(\tau) x(\tau) \int_\tau^\infty W(t)(1 - \varepsilon) F_x(t)\ \tilde{x}^*(\tau, t) dt\, d\tau}{\int_r^\infty F_x(\tau') x(\tau') d\tau'}. \tag{B17}$$

After interchanging the order of integration in Equation (B17) the RHS of Equation (2) becomes

$$\varepsilon \frac{C_x R_x}{N} - \varepsilon K_x$$
$$= \varepsilon(1 - \varepsilon) \int_r^\infty W(t) F_x(t) \int_r^t F_x(\tau) x(\tau)\ \tilde{x}^*(\tau, t) d\tau dt - \varepsilon \int_r^\infty W(t) F_x(t) x(t) dt. \tag{B18}$$

By equating the RHSs of Equations (B8) and (B18) it can be seen that it is sufficient to substantiate

$$(1 - \varepsilon) x^*(t) - x(t) = \varepsilon(1 - \varepsilon) \int_r^t F_x(\tau)\, x(\tau)\, \tilde{x}^*(\tau, t)\, d\tau - \varepsilon x(t),$$

i.e., Equation (B12), to justify Equation (2).

Proof of Equations (B11) and (B12)

Let the LHSs of Equations (B11) and (B12) be

$$\Phi(t) = x^*(t) - x(t)$$

and

$$\Psi(t) = y^*(t) - y(t)$$

and also let the RHSs of these equations be

$$\Phi(t) = \varepsilon \int_r^t F_x(\tau)\, x(\tau)\, \tilde{x}^*(\tau, t)\, d\tau$$

and

$$\Psi(t) = \varepsilon \int_r^t F_x(\tau)\, x(\tau)\, \tilde{y}^*(\tau, t) d\tau .$$

Therefore from Equations (8), (9), (B4) and (B5)

$$\frac{d\Phi(t)}{dt} = -\alpha(t)\Phi(t) + b(t)\Psi(t) + \varepsilon F_x(t)x(t) \tag{B19}$$

and

$$\frac{d\Psi(t)}{dt} = q(t)\Phi(t) - s(t)\Psi(t). \tag{B20}$$

The functions $\Phi(t)$ and $\Psi(t)$ have unique solutions to Equations (B19) and (B20) for initial conditions $\Phi(t=r) = 0$ and $\Psi(t=r) = 0$.

Furthermore,

$$\begin{aligned}\frac{d\underline{\Phi}(t)}{dt} &= \varepsilon \int_r^t F_x(\tau)\, x(\tau) \frac{\tilde{x}^*(\tau, t)}{dt} d\tau + \varepsilon F_x(t)\, x(t)\, \tilde{x}^*(t, t) \\ &= -\varepsilon\alpha(t) \int_r^t F_x(\tau)\, x(\tau)\, \tilde{x}^*(\tau, t)\, d\tau + \varepsilon b(t) \int_r^t F_x(\tau)\, x(\tau)\, \tilde{y}^*(\tau, t)\, d\tau + \varepsilon F_x(t)\, x(\tau) \\ &= -\alpha(t)\underline{\Phi}(t) + b(t)\underline{\Psi}(t) + \varepsilon F_x(t)x(t), \end{aligned} \tag{B21}$$

as $\tilde{x}^*(t,t) = 1$. Additionally,

$$\begin{aligned}\frac{d\underline{\Psi}(t)}{dt} &= \varepsilon \int_r^t F_x(\tau)\, x(\tau) \frac{\tilde{y}^*(\tau, t)}{dt} d\tau + \varepsilon F_x(t)\, x(t)\, \tilde{y}^*(t, t) \\ &= \varepsilon q(t) \int_r^t F_x(\tau)\, x(\tau)\, \tilde{x}^*(\tau, t)\, d\tau - \varepsilon s(t) \int_r^t F_x(\tau)\, x(\tau)\, \tilde{y}^*(\tau, t)\, d\tau \\ &= q(t)\underline{\Phi}(t) - s(t)\underline{\Psi}(t), \end{aligned} \tag{B22}$$

as $\tilde{y}^*(t,t) = 0$.

The linear differential Equations (B19) and (B20) for $\Phi(t)$ and $\Psi(t)$ are identical to Equations (B21) and (B22) for $\underline{\Phi}(t)$ and $\underline{\Psi}(t)$ and the initial conditions are also equal. Therefore $\Phi(t) = \underline{\Phi}(t)$ and $\Psi(t) = \underline{\Psi}(t)$, thus proving Equations (B11) and (B12) and so justifying Equations (1) and (2).

APPENDIX C
ASSESSING THE EFFECT OF ONE PULSE FISHERY UPON ANOTHER: AN EXACT SOLUTION WHEN NO FISH ARE RE-RELEASED

Consider two separate fishing grounds X and Y. Assume fishing takes place during a short period at the same time each year for both fisheries. For fish of a particular cohort, let P_{x1} fish of age 1 year and P_{x2} fish of age 2 years be recruited to ground X just before the corresponding fishing season. The numbers, P_{y2} and P_{y3}, of fish recruited to ground Y are similarly defined.

Proportions f_{x1} and f_{x2} of fish aged 1 and 2 years respectively, are caught by fishers in ground X and proportions f_{y2} and f_{y3} of fish aged 2 and 3 years are caught by fishers in ground Y. The survival parameter S_{xx1} is the fraction of fish initially in X and remaining in X which survives from the beginning of season 1 to the beginning of season 2, i.e it includes the effect of fishing, migration and natural mortality. Parameter S_{xy1} is the proportion of fish of age 1 in X that moves to Y and survives to age 2. Parameters S_{xy2} and S_{yy2} are similarly defined. It is assumed that natural mortality and migration can be ignored during the short fishing season.

The numbers of fish in the commercial catches are $\boldsymbol{C_{x1}}$, $\boldsymbol{C_{x2}}$, C_{y2} and C_{y2}. Symbols in **bold** represent numbers of fish that need to be observed, or estimated by some means, which are the input information into the interaction estimation procedure.

The purpose of this analysis is illustrate how to estimate the effect on the catch numbers of Y of closing down fishery X when no tagged fish are re-released. It is assumed that the mortality parameters are independent of population size and that 1 and 2 year old fish in X can be identified with sufficient accuracy. We construct a table of the numbers of fish caught under the existing fishing regime.

Table C1. The commercial catch numbers of the present fishing regime, by age and fishing ground, in terms of recruitment, survival and fishing intensity.

Ground caught	Catch numbers at age 1	2	3
X	$\boldsymbol{C_{x1}}$ $P_{x1}f_{x1}$	$\boldsymbol{C_{x2}}$ $\{P_{x1}S_{xx1}+P_{x2}\}f_{x2}$	
Y		C_{y2} $\{P_{x1}S_{xy1}+P_{y2}\}f_{y2}$	C_{y3} $\{P_{x1}S_{xx1}+P_{x2}\}S_{xy2}f_{y3}$ $+\ \{P_{x1}S_{xy1}+P_{y2}\}S_{yy2}f_{y3}+P_{y3}f_{y3}$

Suppose fishing ceases in X, but fishing mortality rates in Y, natural mortality rates and migration rates remain unchanged. Let the new survival parameters in fishery X be S'_{xx1}, S'_{xy1} and S'_{xy2}. With this scenario deaths are due to natural causes only, consequently

$$S_{xx1} = S'_{xx1}(1-f_{x1}) \quad \text{or} \quad S'_{xx1}-S_{xx1} = S_{xx1}f_{x1}/(1-f_{x1}), \tag{C1}$$

$$S_{xy1} = S'_{xy1}(1-f_{x1}) \quad \text{or} \quad S'_{xy1}-S_{xy1} = S_{xy1}f_{x1}/(1-f_{x1}), \tag{C2}$$

and

$$S_{xy2} = S'_{xy2}(1-f_{x2}) \quad \text{or} \quad S'_{xy2}-S_{xy2} = S_{xy2}f_{x2}/(1-f_{x2}). \tag{C3}$$

The table of catches for the changed fishing regime is

Table C2. After closing down fishery *X*: the commercial catch numbers by age, in terms of assumed recruitment, survival and fishing intensity.

Ground caught	Numbers in the catch at age 1	2	3
X	C'_{x1}	C'_{x2}	
	0	0	
Y		C'_{y2}	C'_{y3}
		$\{P_{x1}S'_{xy1}+P_{y2}\}f_{y2}$	$\{P_{x1}S'_{xx1}+P_{x2}\}S'_{xy2}f_{y3}$ + $\{P_{x1}S'_{xy1}+P_{y2}\}S_{yy2}f_{y3}$ + $P_{y3}f_{y3}$

It readily follows that the increase in the number of fish caught in *Y* is

$$\Delta C_y = P_{x1}f_{y2}\{S'_{xy1}-S_{xy1}\} + P_{x1}f_{y3}\{S'_{xx1}S'_{xy2}-S_{xx1}S_{xy2}\} + P_{x2}f_{y3}\{S'_{xy2}-S_{xy2}\} + P_{x1}S_{yy2}f_{y3}\{S'_{xy1}-S_{xy1}\} \quad \text{(C4)}$$

Note: this estimator does not involve P_{y2} or P_{y3}.

Tagging experiment

Just before the fishing season begins tag N_{x1} one year olds in X and a year later tag N_{x2} two year olds in the same ground. The number recaptured from ground *X* at age *j* from fish tagged at age *i* is r_{xij}. A similar definition applies to r_{yij}. It is assumed that the age of a fish is known at release with sufficient accuracy, if fish are young this could be determined from length-frequency modes. The numbers of recaptures expressed in terms of population parameters are:

Table C3. The numbers of recaptures of tagged fish of the present fishing regime, by age of release and by age and fishing groundof recapture, in terms of numbers tagged, survival and fishing intensity.

Number tagged	Ground recaptured	Numbers of recaptures at age 1	2	3
N_{x1}	*X*	r_{x11}	r_{x12}	
		$N_{x1}f_{x1}$	$N_{x1}S_{xx1}f_{x2}$	
	Y		r_{y12}	r_{y13}
			$N_{x1}S_{xy1}f_{y2}$	$N_{x1}S_{xx1}S_{xy2}f_{y3}$ + $N_{x1}S_{xy1}S_{yy2}f_{y3}$
N_{x2}	*X*		r_{x22}	
			$N_{x2}f_{x2}$	
	Y			r_{y23}
				$N_{x2}S_{xy2}f_{y3}$

Express Equation (1) as

$$\Delta C_y = \frac{C_x R_y}{N}, \qquad \text{(C5)}$$

where ε is put equal to one and R_y is the number of tagged fish caught by Y in the ideal experiment, will allow us to determine the effect that closing fishery X has upon the numbers of fish in the commercial catch of Y. For the particular year-class under study, the commercial catch of X is composed of C_{x1} age 1 fish and C_{x2} age 2 fish caught a year later, i.e., $C_x = C_{x1} + C_{x2}$. Note that $N_{x1}C_{x2}/C_{x1}$ fish need to be tagged in year 2 to satisfy Condition 5 of the experimental design, but N_{x2} were tagged instead. So $C_x/N = C_{x1}/N_1$. Consequently, if all other requirements of the experimental design are met, the number of recaptures by Y (r_{y23}) needs to be multiplied by $N_{x1}C_{x2}/(C_{x1}N_{x2})$.

We now deal with non-compliance with the re-releasing requirement. Firstly, at the end of season i some N_{xi}-r_{xii} fish remain of the N_{xi} initially tagged at the beginning of the season. If all fish had been re-released then N_{xi} would have remained. To allow for this discrepancy, subsequent recaptures of these fish should be multiplied by the factor $N_{xi}(N_{xi}-r_{xii})$ or $1/(1-f_{xi})$. Accordingly $(r_{y12} + r_{y13})N_{x1}/(N_{x1}-r_{x11}) + r_{y23}N_{x1}N_{x2}C_{x2}/[C_{x1}N_{x2}(N_{x2}-r_{x22})]$ will contribute to R_y.

Next, from the N_{x1} fish tagged in year 1 some $r_{x12}\,N_{x1}/(N_{x1}-r_{x11})$ should have been caught in X at age 2 and re-released, but were not. These need to be represented by the N_{x2}-r_{x22} tagged fish that remain after season 2 from the N_{x2} tagged just before it began. So the additional contribution to R_y is $r_{x12}\,r_{x23}N_{x1}/[(N_{x1}-r_{x11})(N_{x2}-r_{x22})]$.

Consequently, from Equation (C5) the estimate of the change in the catch of Y in terms of observed fish numbers is

$$\Delta C_y = C_{x1}[r_{y12} + r_{y13} + r_{x12}r_{y23}/(N_{x2}-r_{x22})]/(N_{x1}-r_{x11}) + C_{x2}r_{y23}/(N_{x2}-r_{x22}). \qquad \text{(C6)}$$

From Equations (C1 - C3), and Tables (C1) and (C3) the RHS of Equation (C6) becomes

$$P_{x1}\{S'_{xy1}-S_{xy1}\}f_{y2} + P_{x1}f_{y3}\{S'_{xx1}-S_{xx1}\}S_{xy2} + P_{x1}S_{yy2}f_{y3}\{S'_{xy1}-S_{xy1}\} + P_{x1}f_{y3}\{S'_{xx1}-S_{xx1}\}\{S'_{xy2}-S_{xy2}\} + [P_{x1}S_{xx1}+P_{x2}]f_{y3}\{S'_{xy2}-S_{xy2}\},$$

which simplifies to the RHS of Equation (C4) as required. Thus we have illustrated how to make mathematical adjustments when the ideal experiment is not implemented. In fisheries with more complex dynamics the mathematical adjustments may need to be expressed as an iterative process to allow computer analyses.

It is noted one cannot solve for all model parameters because there are 6 equations represented in Equation (C1) and Table (C3) with 8 unknowns: $f_{x1}, f_{x2}, f_{y2}, f_{y3}, S_{xx1}, S_{xy1}, S_{xy2}$, and S_{yy2}. Other information contributes equal numbers of equations and unknowns.

Equations can be adjusted to estimate the change in the weight of fish caught by fishery Y. Additionally, this analysis could also be extended to allow f_{x1}, and f_{x2} to be control variables, e.g. $f_{x1} = 0$ is the conventional size limit case. It could also be extended to cases where more age classes are harvested in X and/or Y or where fish are tagged in both grounds.

A METHOD TO ESTIMATE MOVEMENT FROM CHANGES IN ESTIMATED DISTRIBUTIONS, AND THEN REVISE THOSE ESTIMATES

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ABSTRACT[1]

A simple procedure is described for directly estimating diffusion coefficients, which may vary both spatially and temporally, from changes in the spatial distribution of an index of abundance. Estimates of distributions of mobile organisms are not usually known with great accuracy, but the speed of individuals places a constraint on changes in distribution. This constraint can be used to revise the estimates of distribution. Estimates of the matrix of diffusion coefficients are used to re-evaluate the distribution of abundance by explicitly linking the estimation of movement and distribution in a single program. It is possible to infer estimates of distribution and movement in periods for which particular zones are not sampled.

These methods have been developed as part of a study of yellowfin tuna in the eastern Pacific Ocean, and are illustrated with data from that fishery. The same method could be applied to study other fisheries and organisms.

[1] Full paper to be published elsewhere.

AN AGGREGATE MODEL OF EFFORT DISTRIBUTION FOR THE EASTERN PACIFIC TUNA FISHERY

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ABSTRACT

A simulation model of the spatial distribution of fishing effort in the eastern Pacific tuna fishery is introduced. The model represents the changes in distribution of total effort as a function of perceived changes in relative abundance of the resource. Several stratification schemes allow us to refine the resolution of the model to account for major heterogeneity in fleet composition. Possible parameterisations of the basic model and associated estimation procedures for its parameters are also discussed. In the eastern Pacific fishery, the model performed reasonably well in predicting average distributions of purse seine effort. Potential expansions of the basic model include individual-based models, currently under development.

1. INTRODUCTION

Simulation models can provide valuable insights in assessing the importance of interactions between fisheries, since they allow us to summarise our current level of knowledge and formulate predictions that can be compared against observations. For example, hypothetical scenarios can be explored that depart radically from past situations, such as large changes in fishing strategies that might result in changes in fishing mortality patterns. In the case of the eastern tropical Pacific fishery (ETP), the Inter-American Tropical Tuna Commission (IATTC) developed a simulation model to assess potential interactions that might result from large changes in the relative importance of the different fishing modes (fishing in association with dolphins, fishing on floating objects or fishing free-swimming schools of tuna) (see Mullen et al., 1996) for a description of the main simulation model). In this context, a fishery interaction is defined as the potential changes in yield by one sector of the fishery due to the activities of another component of the fleet.

Under those circumstances, large departures in the spatial distribution of effort relative to the traditional patterns can be expected. In synthesis, the question is: how are fishermen going to spatially reallocate their effort if certain fishing tactics (traditionally associated with specific time-area strata) are abandoned?

In order to answer this question, we need to model the distribution of fishing effort as a function of the information available to the fishermen about the distribution of the resource. This implies that, as in any model of distribution of fishing effort, there are two processes

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that need our attention: 1) modelling the amount and distribution of the information among the fishermen, and 2) modelling the response of the fishermen to the available information. In this paper, the model implemented as part of the simulation model described by Mullen et al. (1996) is reviewed. In this model, effort is represented as an aggregate variable, aggregated over boats within a particular flag and vessel-size categories. The distribution of effort in the model changes spatially at certain time intervals, according to the existing perception of the local distribution of the resource.

Similar approaches for the spatial modelling of effort have been proposed in the past, with some variations. Caddy (1975) used a similar representation of the effort in a model of shellfish fisheries, Hilborn and Walters (1987) proposed the same basic approach when discussing fishery modelling with spatial structure. Gillis et al. (1993) discuss general principles that lead to aggregated models.

These models are suitable for situations where we do not have detailed information about the daily activities of the vessels. The data requirements are relatively low, and they represent a useful first step in modelling fleet dynamics. However, the models are too simple to reflect the consequences of individual variability in fishing strategies. Processes such as the sharing of information among fishermen or different attitudes towards risk might not be easily incorporated in these models.

Table 1. Summary list of the assumptions implicit in the model.

• Fishing effort is defined as number of days/boats, i.e., no individual vessels are identified.
• Effort is stratified into categories related to vessel size, fishing mode and groups of nations.
• Effort is spatially allocated by 2.5-degree cells and assumed to be distributed randomly within a 2.5-degree cell.
• Total level of effort is constrained to the observed level for the month.
• Effort is re-allocated once a day.
• In a day, effort can move only within a local area defined by the original cell and the eight neighbouring 2.5-degree cells.
• Costs of moving within the local area are negligible.
• Information regarding the fishing conditions is updated every six days.
• Information is perfect regarding the catch rates of vessels from the same effort category in the local area.
• No information is available from cells beyond the local area.
• Redistribution of effort in the local area is done proportionally to the catch rates experienced in the previous week.

2. AN OUTLINE OF THE MODEL

The main assumptions of the model are listed in Table 1. In the model, effort is assumed to be an aggregated variable being reallocated dynamically according to the changes in the local conditions of the fishery. Fishing effort is defined as the numbers of

days fishing multiplied by the number of boats, that is, a unit of effort is one boat fishing one day. The spatial resolution is set to a 2.5-degree cell, in accordance to the spatial resolution of the population processes incorporated into the main simulation (Mullen et al., 1996).

Modelled effort is stratified into classes related to vessel size and fishing strategy: 1) boats of less than 900 tons of carrying capacity; 2) boats above 900 tons; and 3) boats that usually do not fish in association with dolphins. Within these categories, effort was further subdivided into three fleets corresponding approximately to the different coastal regions of the ETP, and a fourth fleet for non-coastal nations.

The total spatial range of the fishery in the model, assumed to comprise 327 2.5-degree cells was divide into five areas: four that represent the economic exclusive zones of groups of coastal nations and a fifth area, that represents international waters. This stratification was used as a way to represent some of the logistic restrictions that small vessels face (they cannot go too far from port), and also as a way to explore potential consequences of changing fishing patterns (like restricting access to certain areas).

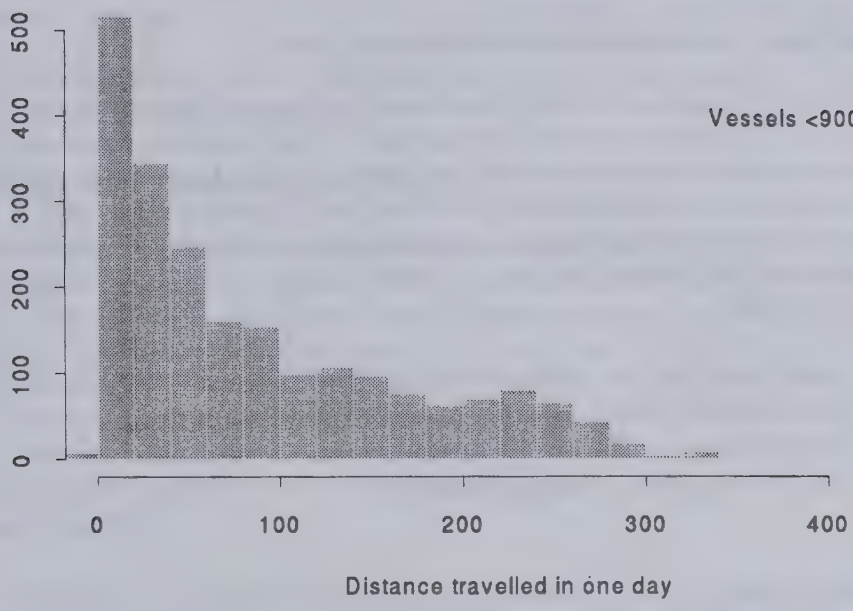
In the model, effort has a certain initial distribution in space depending on fishing mode, fleet and vessel-size class. Starting from these initial conditions, effort is allowed to change spatially and, in principle, between fishing modes, following a set of rules that establish a relation between the local situation of the fishery and the rates of flow of effort. Monthly total effort by fleet and vessel size class remains constant and equal to the observed levels for the month, that is, temporal fluctuations of total effort levels are not modelled.

The time resolution of the effort allocation model is set to one day. In one day, modelled effort from one cell can move only to the eight surrounding cells or stay in the original cell. This is equivalent to assuming that vessels cannot move further than approximately 225 miles on any day, which on average corresponds to the observed movement rates of the vessels. In Figure 1 the distribution of distances between noon positions of consecutive days for all vessels in 1994 is shown. The proportion of distances that are lower than 225 miles is over 90% for vessels less than 900 tons, and 86%, for vessels larger than or equal to 900 tons, which indicates that the applied restriction in movement is reasonable.

The rule for reallocating the effort is based on the relative fishing success in the area in the previous weekly period ("weeks" are defined as a fifth of a month in the simulation model). This represents the information state of the fishermen, that is, the model assumes that fishermen are using this information to decide on where to fish.

At the end of a day, the amount of effort spent in any single cell is redistributed in the local area (defined as the original cell and its eight neighbours) proportionally to the catch rates experienced (within the same fleet and size classes) in the previous week. Implicit in this rule is the assumption that vessels have precise information about the conditions in the local area and no information about areas further away. Also, vessels are assumed to update their information state only once a week, and that information retains its value until

new information is available (i.e., vessels respond in the same way to the same information throughout the week).



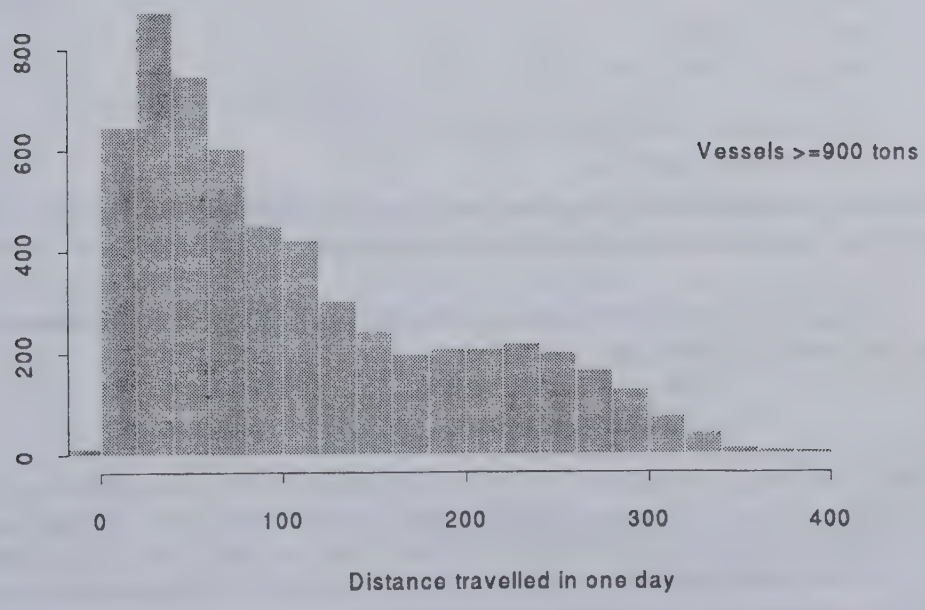


Figure 1. Distribution of distances between noon positions of purse-seine vessels, data from 1994.

The costs of moving in the local area are assumed negligible, that is, there is no additional cost in moving to an adjacent area rather than staying in the original cell. The actual implementation of this model requires two steps: 1) computing the expected revenue or value per unit effort (VPUE) as a function of location and fishing modes, and 2) re-distributing the effort proportionally to some function of the expected VPUE. We will review each of these in the next sections.

2.1. First Step: Computation of the information State

In the model, it is assumed that the information that fishermen have about the desirability of each location is based on the expected VPUEs, which are essentially the catch rates (measured in landed value) from the previous week. These represent the landed value of the expected catch composition, and depend on the local abundance and catchability of the yellowfin semi-annual age groups and the abundance of skipjack, and on the value (price) of the different fish sizes. Therefore, separate VPUEs are calculated for yellowfin and skipjack.

In the case of yellowfin, for which we have an age-structured representation in the general simulation model, we have, for a given period or week;

$$Y_{ifg} = \sum_c N_{ic} q_{icfg} w_c p_y(w_c) \qquad (1)$$

where

i = 2.5 degree cell,
c = a cohort (semi-annual age group),
f = a fleet category
g = a vessel-size category,
Y_{ifg} = yellowfin catch rate in commercial value,

N_{ic} = is the abundance in numbers for cohort c in cell i,
q_{icfg} = is a catchability coefficient,
w_c = average weight of a individual from semi-annual age group c, and
$p_y(w_c)$ = ex-vessel price of a unit of weight of a yellowfin from cohort c.

For skipjack, we do not have an age-structured model of abundance and, therefore, we model the relative abundance as

$$Z_{ifg} = U_{ifg} p_s(w) \qquad (2)$$

where

Z_{ifg} = skipjack catch rate in commercial value,
U_{ifg} = skipjack catch rate, and
$p_s(w)$ = ex-vessel price of a unit of weight of skipjack,

Finally, the overall value for the cell, is computed as:

$$V_{ifg} = Y_{ifg} + Z_{ifg} \qquad (3)$$

That is, the value assigned to any 2.5-degree cell is the sum of the expected values for skipjack and yellowfin. The value for yellowfin is a sum of the abundance of the different cohorts present in the cell, weighted by the catchabilities (specific to the cohort, set type, fleet and vessel size), average weight and price per unit weight. Thus defined, the values V represent the average economic gross revenue that could be obtained from a particular 2.5-degree area by a unit of effort of a given fleet and vessel-size class. These values, computed at the beginning of each reallocation period for each cell, are the driving force behind the effort reallocation algorithm.

2.2 Second Step: Redistribution of the Effort

Once we have a map of the values that define the desirability of each area, we need to devise a procedure for reallocating the effort. Again, there are several possible ways to proceed. In one approach, we could redistribute the effort over the entire fishery. However, this would be equivalent to assume that vessels can move over large areas without any cost or time restriction in the time step chosen in the model (a week). Therefore, we must incorporate some restrictions to the movement allowed in one time step. As we mentioned above, we took the alternative approach of distributing the effort from a given 2.5-degree cell, i, in the local area Ω_i, determined by the cell itself and its eight adjacent neighbours.

Let us denote by $e_{ifg}(t)$ the amount of effort in time t and cell i (the source cell). This effort will be redistributed in each of the j target cells, which are those in the neighbourhood

$$\Omega_i\ (j \in \Omega_i), \text{ according to } e_{(i\to j)fg}(t+1) = e_{ifg}(t)\frac{V_{jfg}}{\sum_{j\in\Omega_i} V_{jfg}} \qquad (4)$$

That is, effort from any source cell is pro-rated among the surrounding cells according to the relative local VPUE. The effort in any cell will be the sum of contributions from the other cells in the neighbourhood Ω_i. Therefore, the final effort in cell i, for flag group f and size class g fishing in mode s during period $t+1$, is obtained from

$$e_{ifg}(t+1) = \sum_{j\in\Omega_i} e_{(j\to i)fg}(t+1) \qquad (5)$$

This reallocation procedure is repeated for all cells in the area of the modelled fishery that are admissible. An example of non-admissible cells are those that are outside the area defined by the 327 cells. They are not included in the above calculations and, as a consequence the boundaries of the region operate as reflective boundaries.

The procedure is repeated six times and the distribution of effort at the end of the six time steps is the one used to calculate the catches in the main simulation model. The reason for choosing six steps is not arbitrary but related to the assumption that vessels do

not move more than 2.5 degrees in any direction in one day. Since in the main simulation model the catches are only calculated every fifth of a month (roughly six days), the effort is allowed to move for those six days. Therefore, although the effort can only propagate one cell at each time step, it can cover a much larger distance (up to six 2.5-degree cells) before the information state (and all the other processes in the main simulation) are updated.

The basic reallocation procedure relates to the model used by Caddy (1975). The main difference is that the historic distribution of effort is not taken into account, and that the re-distribution is done locally rather than on the basis of global information. The resulting distribution tends to an equilibrium close to that of the ideal free distribution model (Gillis et al., 1993), in which we have effort distributed approximately proportional to the relative abundance. Therefore, a mechanistic interpretation analogous to that allowed by these two models applies to our allocation procedure. Namely, that the main assumption is that the probability that a unit of effort moves to a given square in the local region is proportional to the relative catch rates experienced in the previous time period.

3. RESULTS

Originally, the general algorithm described above included a partition of the effort among fishing modes, that is, modelled effort was not only redirected spatially, but the switching between fishing modes was modelled as well. However, in some of the earlier trials of the models it became obvious that modelling this side of the fishing strategy was not going to be possible, at least at this stage. Modelled effort showed a strong tendency to switch to fishing on free-swimming schools and on floating objects. This is not surprising since log sets have high catch rates and both fishing modes are often associated with large catch rates for skipjack, which raises the value attached to those fishing modes. Part of the problem originates in the way the skipjack population is represented in the model. As there is a current lack of knowledge about the population dynamics of this species in the eastern tropical Pacific, a very simple model of the skipjack dynamics was used. This model does not incorporate local depletion of the population (in contrast with the yellowfin model) and, therefore, there is no limit to the catch that could be obtained by increasing effort. Large amounts of modelled effort tended to drift towards those two strategies, because skipjack catchabilities are higher in school and log fishing than in dolphin-associated fishing.

Therefore, the proportion of effort going into each fishing mode was constrained to be equal to the observed proportions of effort in the fishing modes allowed under a given simulation scenario. For example, a non dolphin-fishing scenario would contain effort split among log and school fishing modes in accordance with their relative proportions. In general, the model described by equation (4) shows a moderately good fit between the observed and modelled distribution of effort, as it can be seen from the maps in Figures 2-4. Those maps show the distribution of modelled effort on the left panels and the distribution of observed effort on the right panels. In Figure 5, the correlation between observed and modelled effort over the simulated period (1980-86) is shown. The correlation was computed on the basis of the total effort by 2.5-degree cells for a given month. The pattern of these correlations indicate that the model can mimic the distribution of effort reasonably well in the first three years, 1980 through 1982. The performance of the model is worse in 1983 and the beginning of 1984. This is most likely related to the

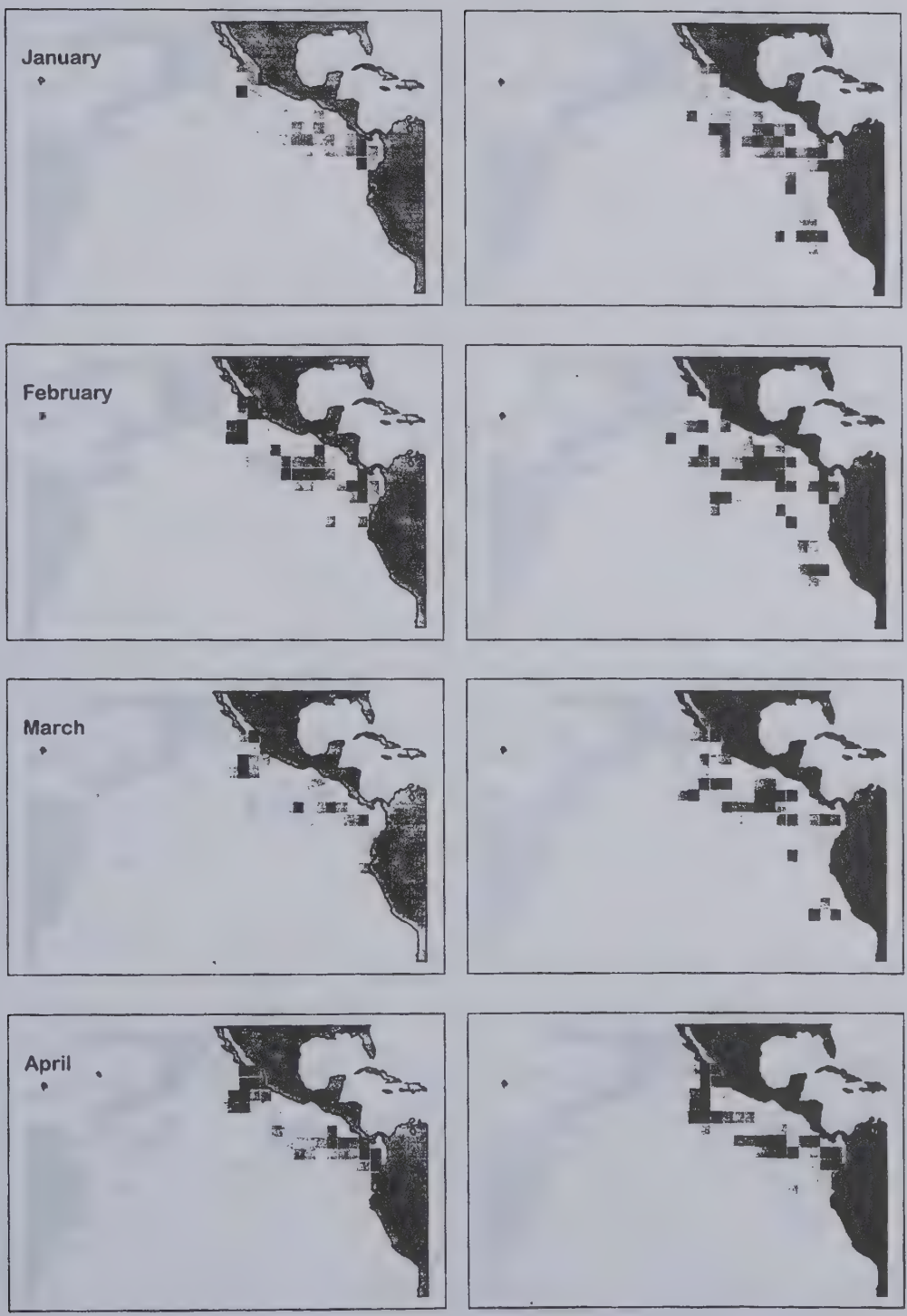


Figure 2. Distribution of predicted (right panels) and observed (left panels) fishing effort by month, over the period 1980-86, January through April.

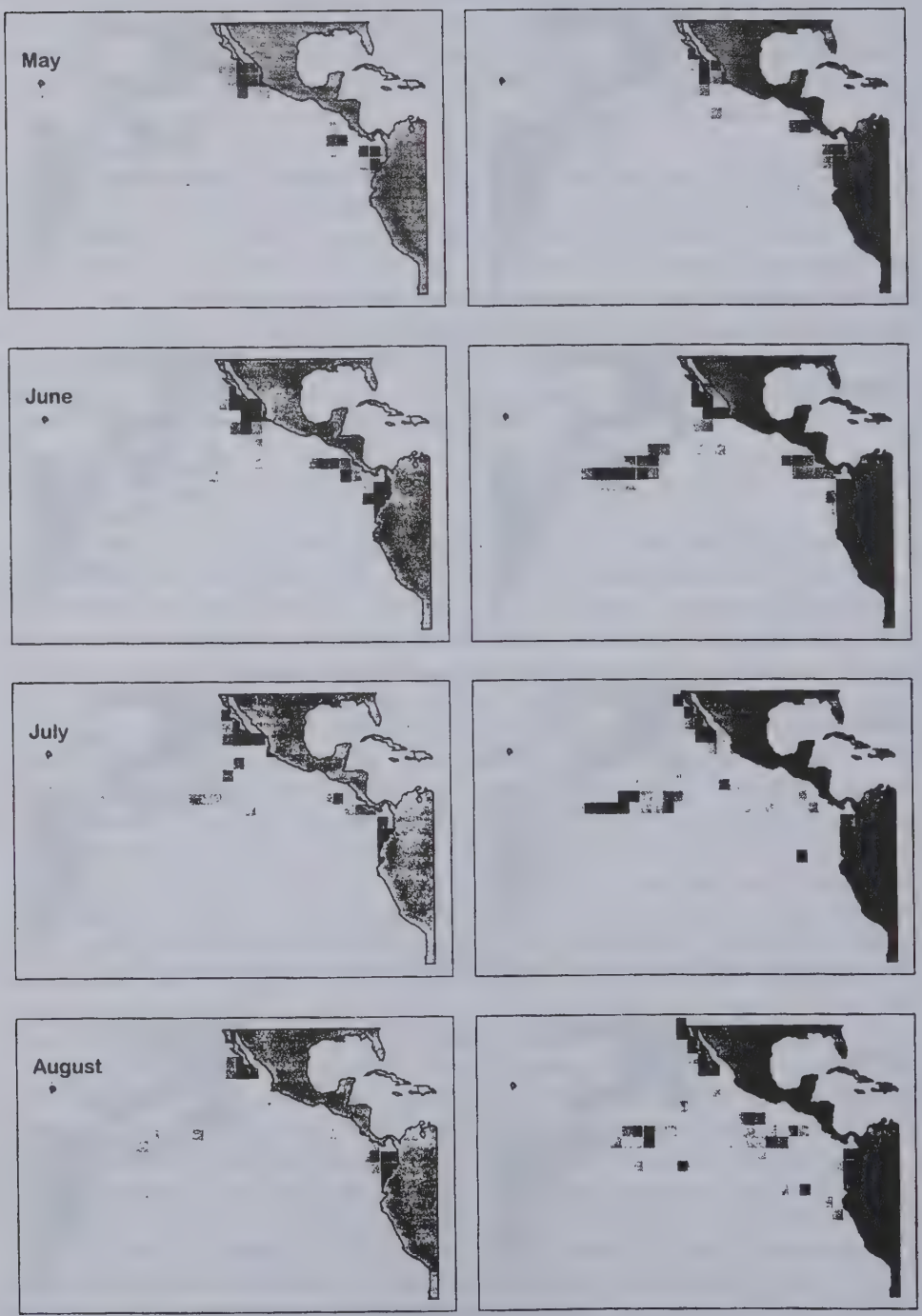


Figure 3. Distribution of predicted (right panels) and observed (left panels) fishing effort by month, over the period 1980-86, May through August.

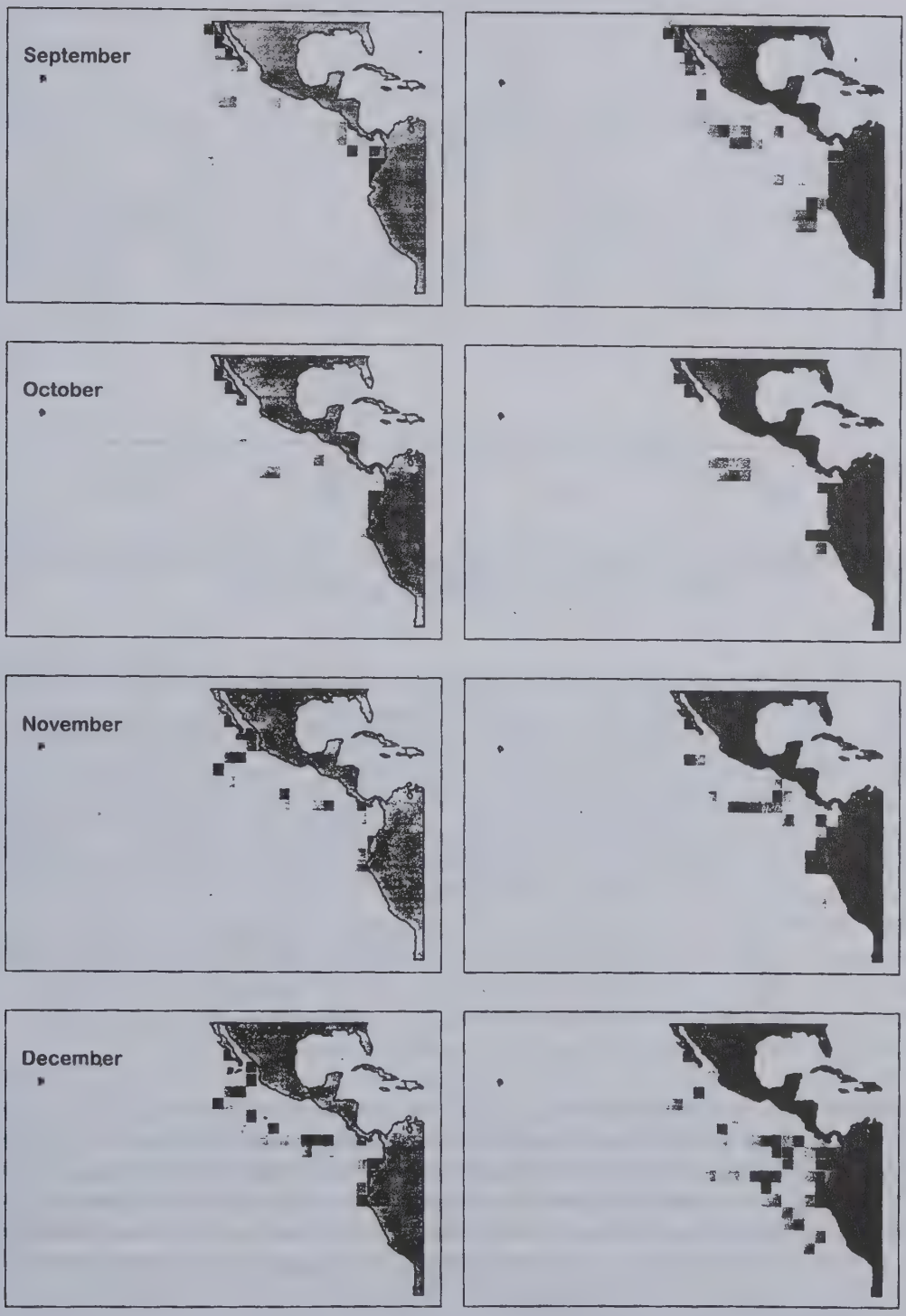


Figure 4. Distribution of predicted (right panels) and observed (left panels) fishing effort by month, over the period 1980-86, September through December.

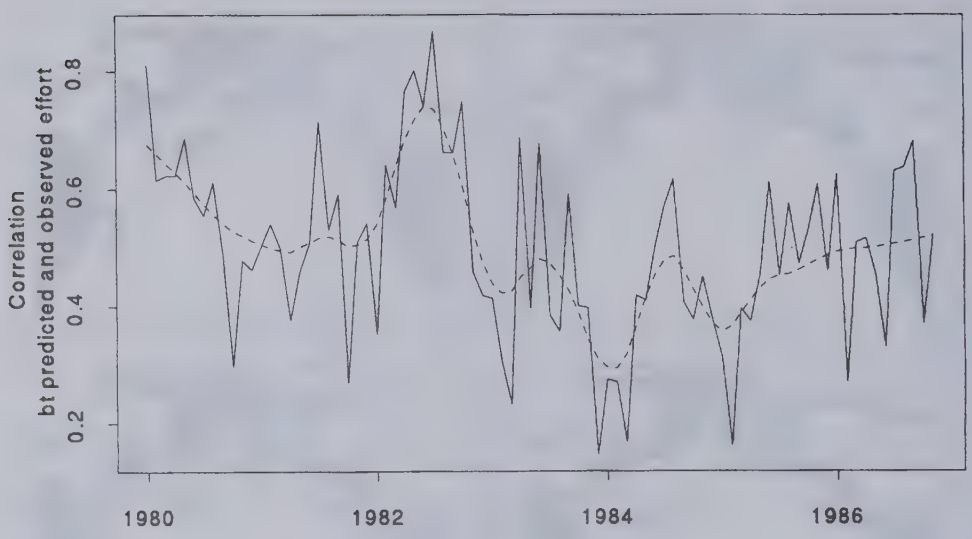


Figure 5. Monthly correlations between observed and predicted effort for the period 1980-86. The dotted line is a smoothed line to highlight the trends.

major changes in the distribution of the resource that took place as a consequence of a very strong El Niño event. Effort was more dispersed during this period as a consequence of the unusual distribution of the fish that made it more difficult for the fishermen to locate the good fishing areas. This resulted in many areas with low observed catchabilities that slow down the dispersal of effort in the model. Beginning in 1984, the agreement between the predicted and the observed distribution improves gradually until it reaches in 1985 and 1986 levels similar to those for the 1980-81 period. The distribution of the discrepancies by month (Figure 6) shows that the main disagreements are concentrated in the months of October and November. This problem probably originates in the apparent inability of the model to predict well the seasonal occurrence of a traditional good fishing area close to the coast of South America. The low correlation shown for the month of March originates from a single cell with very high effort (see Figure 1), which is the consequence of an extraordinary event in 1984 where most of the catch originated in that cell.

The lack of fit in the southern area points to one of the weaknesses of the procedure as implemented: the problem is that the catchabilities are based on monthly data on catch and abundance, rather than averaged over a longer period. This restricts the movement of the modelled effort: only those 2.5-degree cells where there was some catch for a given month are candidates to receive effort since these are the only ones that have positive catchabilities (and, therefore, non-zero values). If areas (such as the mentioned southern area) are surrounded by areas of zero (or near-zero) catchability, effort is never (or seldom) able to diffuse into them.

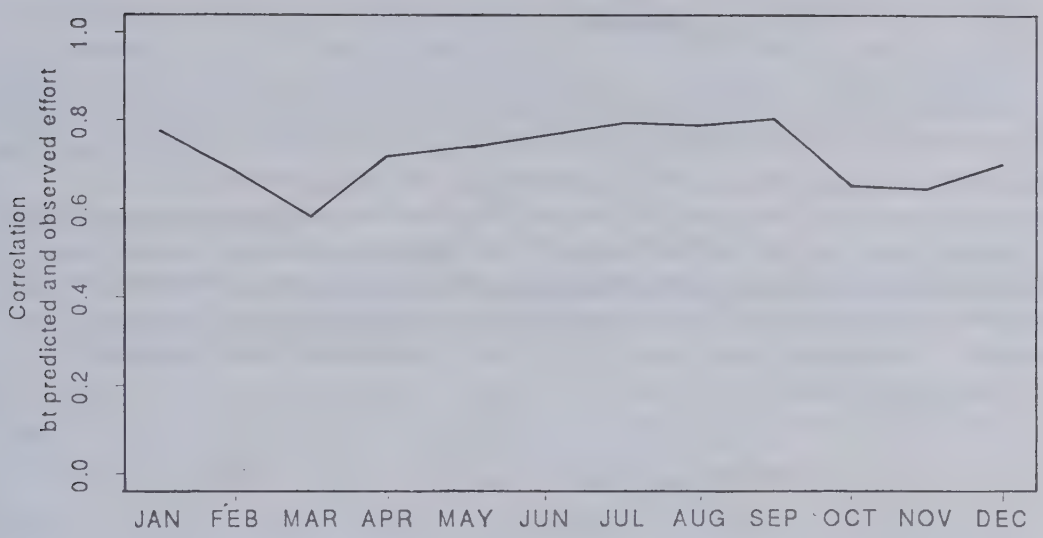


Figure 6. Correlations between observed and predicted effort for the period 1980-86, pooled by month.

4. CONCLUSIONS

The approach to model fleet dynamics presented here allows several variations. In the ETP simulation model, the distribution of effort was assumed to be proportional to the *VPUE*s, that is, according to equation (4). However, this is not the only way of parameterising the model. In principle we can take some functional of the VPUEs that would provide a better fit to the observed distribution of effort. There are several ways in which to set up the problem to allow for some parametric control.

For example, we can take a power function of the values, such as

$$V'_{ijg} = aV^{b}_{ijg} \qquad (6)$$

where the parameters a and b can be estimated from the data. For values of $b > 1$, effort will tend to concentrate more on the locations that have the better prospects. The situation where $b < 1$ is equivalent to assuming a certain degree of saturation, that is, that the marginal rate of profit is a decreasing function of value. If the resolution of the data allows it, the proportion of effort going into each target square can be estimated directly through a generalised linear model with a logit link (in our case, we would need the daily information about effort movement and changes in local abundance.)

Alternatively, we could decide that fishermen are only going to move to locations that exceed a certain threshold value, therefore

$$V'_{ifg} = \begin{cases} 0, & \text{for } V_{ifg} < V_0 \\ V_{ifg}, & \text{otherwise.} \end{cases} \qquad (7)$$

This functional must be used with caution because, if V_0 is chosen to be too high, it will reduce the area that effort can move to (effort can only move to places where the $V_{ifg} > 0$). This might create areas that become isolated from the rest of the fishery range: effort cannot enter nor leave these areas. If functionals such as those described in equation (6) or (7) are being used, we need to obtain values for the parameters involved. In some cases, this can be done by either by a linear regression technique (in the case of equation (6), after a suitable transformation), or, more generally, through a least squares minimisation procedure. For example, in the case of the threshold function described by equation (7), we can estimate V_0 by

$$\hat{V}_0 = \arg\min \sum_t \sum_{ifg} \left(f_{ifg}(t) - \hat{f}_{ifg} \right)^2 \qquad (8)$$

Again, there are multiple ways of implementing the estimation. For example, the sum of squares in the above equation is computed on the basis of the effort being projected for the whole modelled period, given a certain set of initial conditions. This is a procedure analogous to an observation error estimator. Alternatively, we can reset the initial conditions at certain intervals and project the effort distribution over shorter periods, similar to a process error estimation procedure. We can also further stratify the data in order to obtain season- or area-specific parameters.

The model presented here has been a useful first approximation to the problem of modelling effort in the ETP. However, the data available for this fishery allows us to go a step further and develop models that would exhibit richer behaviour. Currently, we are in the final stages of developing of a model that represents the decision-making of individual fishermen in the fleet. Such a model allows us to explore a broader range of problems. Both classes of models are based on the same principle: the decisions related to the fishing operations are based on the amount of information available to the fishermen. In practice, we know neither the information state nor the decision rules of the fishermen. This is not unlike the problem in population dynamics models where we do not observe the stock state (a latent variable) but we try to infer it from the realisations of a stochastic process (the catch). Both the population size and the catch are stochastic processes for which we do not know the variability, and therefore some compromising assumptions are necessary. We are forced to make the same kind of compromises in modelling fleet dynamics. The model presented here leans towards conditioning of the information state, assuming that the main source of variability lies in the fishermen's response. A different compromise might yield different results.

In the case of the aggregate model, the interpretation of the discrepancies between predicted and observed effort distribution must be done with caution, because they are complicated by the confounding with some of the other processes modelled in the main simulation that are related to the distribution and abundance of the fish, and that determine the information state of the modelled fleet.

This points to a more general problem with models of effort, essentially that, unless we can approximate well the information that is available to the fishermen, we will not be able to correctly discriminate between the two sources of error. We can be making erroneous assumptions about the fishermen's information state, about their responses to that information, or both.

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A SIMULATION MODEL OF TAGGING EXPERIMENTS FOR YELLOWFIN TUNA IN THE WESTERN INDIAN OCEAN

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ABSTRACT

A simulation model of tagging experiments of yellowfin tuna in the western Indian Ocean was developed. Discrete movements of fish occurring in a five-degree square grid are described by a diffusion parameter. Monte-Carlo data sets were created to estimate confidence limits on the parameters estimated by the model (natural mortality, catchability and diffusion rate). Several levels of number of tagged fish and location of releases were tested. The development of a scheme including two fisheries permitted the calculation of marginal interaction parameters and their precision. For that purpose, a second model dealing with the entire population of yellowfin was also developed. As expected, preliminary results indicate that the precision of the parameters is related to the recovery rate, and that it is better to tag fish in the area with high fishing mortality. Tagging about 10,000 fish should be sufficient to obtain a precision of 10% on all parameters when only one fishery is included in the model. With two fisheries, releasing fish in both fisheries seems the best alternative if good precision is expected on all parameters simultaneously. If tagged fish are released in only one fishery, the precision on the catchability of the other fishery remains low, even with a large number of fish released (up to 20,000). Tagging enough fish in the affected fishery also seems important if we want to assess with good precision the impact of one fishery on the other through marginal interaction coefficients. The impact of adding randomness to the reporting rate was also tested and showed that this parameter can have a strong impact on the precision of the catchability coefficient.

1. INTRODUCTION

The precision of the parameters estimated from a tagging experiment, e.g., natural mortality, fishing mortality and movement patterns, is closely related to the number of fish released. Thus, before designing an experiment, it is useful to know what level of tag releases is required to achieve a certain level of precision on the parameter to be estimated. One way of doing this is to conduct a series of Monte-Carlo simulations of a tagging experiment using one assumed set of parameters and different levels of tag releases. Many synthetic data sets are created using random number generation. Each of them is then used to fit the parameters. The distribution of these fitted parameters around the assumed parameters used to create the synthetic data sets gives an idea of the precision.

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Hampton (1989) carried out such an analysis using two tag attrition models. The first was spatially aggregated and dealt with one fishery, whereas the second involved two fisheries with exchange of fish between them. Although this second model included movements of fish between the fisheries, it did not take account of the distribution of the tagged fish and recoveries in time and space inside each of the fisheries.

The present analysis is an adaptation of Hampton's approach. It uses a tag attrition model incorporating movement parameters. Spatial distribution of tag releases and recoveries are included in the model. Only one fishery (purse seine) is first considered. A more complicated scheme including two fisheries (purse seine + artisanal fishery) is then developed. This second scheme permits the calculation of interaction coefficients and evaluation of their precision.

The objective of this paper is to determine the optimal number of yellowfin to release in a tagging experiment that is scheduled to be conducted in the western Indian Ocean. This methodology can easily be transferred to other geographic areas.

2. THE SIMULATION MODELS

2.1 Generating Tagging Experiment Data and Fitting the Attrition Model (Model I)

The simulation starts with the generation of synthetic data sets. Probabilities associated with the fate of each tagged fish are first calculated, i.e., the probability that it be recovered in a cell (i, j) during each time interval $(t, t+\Delta t)$ and be returned, the probability that it be recovered and returned without relevant information, the probability that it not be returned (due to different causes: tagged fish surviving to the end of the period, death, non-reporting). Sibert and Fournier (1994) and Kleiber and Hampton (1992) give a description of a movement model permitting the calculation of these probabilities. The number of tagged fish in each cell *(i, j)* at each time step is calculated using the following equation:

$$P_{i,j,t+\Delta t} = P_{i,j,t} + \Delta t \cdot \Big[D \cdot (P_{i+1,j,t} + P_{i-1,j,t} + P_{i,j+1,t} + P_{i,j-1,t}) - \left(4D + M + qE_{i,j,t}\right) \cdot P_{i,j,t} \Big] \quad (1)$$

where M is the natural mortality coefficient; q is the catchability, $E_{i,j,t}$ is the fishing effort in cell *(i, j)* at time t and D is the diffusivity parameter. If $P_{i,j,0}$ fish are tagged and released in cell *(i, j)* , the number of fish in that cell entering the first time interval is equal to $\alpha.P_{i,j,0}$ where α is the survival rate from immediate tag loss. Solutions of Equation 1 over time are then generated using the alternating direction implicit method (see Press, et al., 1992, for details on the resolution of the implicit equation). The numbers of tagged fish present in each cell at each time step are used to calculate the number of fish recovered and the number of fish surviving this time step. Dividing these numbers by the number of released fish gives the corresponding probabilities.

To account for non-reporting, the number of tagged fish recovered is multiplied by the reporting rate of recaptured tags β. The number of tagged fish recaptured in cell *(i, j)* at time t and reported $(T_{i,j,t})$ is thus equal to:

$$T_{i,j,t} \approx \beta \cdot F_{i,j,t} \cdot P_{i,j,t}$$

where $F_{i,j,t}$ is the fishing mortality coefficient given by:

$$F_{i,j,t} = q \cdot E_{i,j,t}$$

If a tagging experiment with N releases is to be simulated, N pseudo-random numbers uniformly distributed on (0,1) are generated and the fates of each tagged fish n are determined using a decision-making process with assumed values for parameters (see Hampton (1989) for more details). The operation is performed several times and K data sets $\mathcal{D}_k$ are created. Each of the data sets is used to fit the tag attrition model and to obtain K maximum likelihood parameter estimates. These estimations are carried out using an iterative searching algorithm, the Nelder-Mead simplex algorithm (Press, et al., 1992). Average coefficients of variation can eventually be calculated ($\sigma/\mu \times 100\%$).

2.2 Estimating Interaction Coefficients and Their Precision (Model II)

When two fisheries (artisanal and purse seine) are considered, the results of a tagging experiment can be used to estimate interaction coefficients. One way to do this is to apply values of parameters, estimated from the tagging experiment, to the untagged population of yellowfin. The model dealing with this population is much like the one dealing with tagged fish. A recruitment component is simply added to Model I described by Equation 1. This equation becomes:

$$\begin{aligned} P_{i,j,t+\Delta t} = P_{i,j,t} + \Delta t \cdot \Big[& D \cdot (P_{i+1,j,t} + P_{i-1,j,t} + P_{i,j+1,t} + P_{i,j-1,t}) \\ & - \left(4D + M + \sum_{l=1}^{2} q_l E_{i,j,t}^{l} \right) \cdot P_{i,j,t} + R_{i,j,t} \Big] \end{aligned} \qquad (2)$$

To avoid adding too much complexity to this second model, recruitment is assumed to be constant in time and throughout the area. The initial value for the population in each cell i,j is also constant throughout the area. This gives:

$$\begin{cases} R_{i,j,t} = R \\ \forall i,j,t \end{cases} \quad \text{and} \quad \begin{cases} P_{i,j,0} = P \\ \forall i,j \end{cases}$$

Tuning of Model II is done by choosing an arbitrary value for P and scaling the recruitment level to obtain catches C by fishery at the equilibrium, roughly equivalent to the real average catch.

To define interaction coefficients between fisheries, we used an approach similar to that of Sibert (1984). Those coefficients were calculated by measuring marginal impact of changes in the catch of the affecting fishery on the catch of the affected fishery. In our two-fisheries system, approximations of interaction can be obtained from:

$$I_{ps \to art} \approx \frac{\Delta C_{art}}{\Delta^* C_{ps}} \quad \text{and} \quad I_{art \to ps} \approx \frac{\Delta C_{ps}}{\Delta^* C_{art}}$$

where $\Delta^* C_{art}$ or $\Delta^* C_{ps}$ represents a small change in the catch of the affecting fishery (*art* for artisanal fishery and *ps* for purse seine fishery) and ΔC_{art} or ΔC_{ps} its consequence at equilibrium on the affected fishery.

When simulations using Model II are carried out, small variations in the catch of the affecting fishery are obtained by altering its fishing mortality coefficients F by a given quantity (ΔF). F is calculated using the following equation:

$$F = q \cdot E$$

where q and E are the catchability and fishing effort of the fishery considered. Once the system has found its new equilibrium position, interaction coefficients are calculated as follows:

$$I_{ps \to art} \approx \frac{C_{art}(F_{ps} + \Delta F_{ps}, F_{art}) - C_{art}(F_{ps}, F_{art})}{C_{ps}(F_{ps} + \Delta F_{ps}, F_{art}) - C_{ps}(F_{ps}, F_{art})}$$

and

$$I_{art \to ps} \approx \frac{C_{ps}(F_{ps}, F_{art} + \Delta F_{art}) - C_{ps}(F_{ps}, F_{art})}{C_{art}(F_{ps}, F_{art} + \Delta F_{art}) - C_{art}(F_{ps}, F_{art})}$$

where $C_{art}(F_{ps} + \Delta F_{ps}, F_{\text{art}})$ is the catch of the artisanal fishery when the fishing mortality coefficient of the purse seine fishery is increased (or decreased) by the quantity ΔF_{ps} and the fishing mortality coefficient of the artisanal fishery is left unchanged.

To estimate the distribution of the interaction coefficients, the K sets of $\{M, q_1, q_2, D\}$ obtained from Model I are entered into Model II, K values of interaction coefficients are thus calculated. Average coefficients of variation can be estimated as described above. During that step, estimation of recruitment level is made using average values for the parameters M, q_1, q_2, D.

3. PARAMETERS USED TO CONDUCT THE SIMULATIONS

3.1 Study Area

The study area and fishery are designed to be as similar as possible to reality. The total study area (30°E-80°E, 25°N-35°S) is represented by a grid of 120 five-degree squares (Figure 1). It includes some land masses where the fish are not allowed to go after being released. To insert those land masses in our grid, we simplified the layout of the coast by moving them to fit the squares. Shaded areas in Figure 1 correspond to the simplified land masses. Bold lines represent boundaries where movement coefficients are set to zero. This prevents the fish from crossing them.

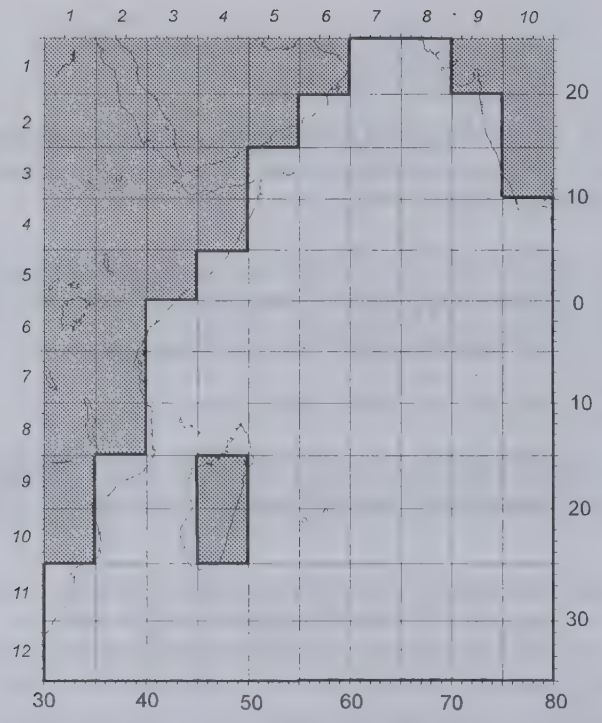

Figure 1. Study area used in the simulations showing land masses (shaded area) and limits of the zone where the tagged fish are allowed to go (bold line).

3.2 Fishing Effort Data

Little information is available on the spatio-temporal distribution of the artisanal fishing effort. The main fleets exploiting yellowfin are situated in the northern part of the region, from the coasts of Somalia to those of Maldives and Sri Lanka (IPTP, 1992). This fishery is mainly composed of gillnetters, except in Comoros where fishing is with pole and line. The spatial distribution of the fleets used in the simulations is presented in Figure 2. This fishing effort is set to 1 in each square where the fleets are situated and assumed to be constant throughout the year.

Monthly fishing effort distribution for the purse seiners (mainly French, Spanish, Japanese and Mauritian) is available by five-degree square for 1992. Fishing effort is expressed as total number of days spent each month in each square; 1992 was considered as typical of the present distribution of fishing effort. Figure 3 shows the distribution of effort for four months. The major part of the fleet of purse seiners is clearly moving significantly from one period to another. From December to March, vessels operate in an area east of Seychelles. They move into the Mozambique Channel in April-May. From July to November they shift to the north of Seychelles.

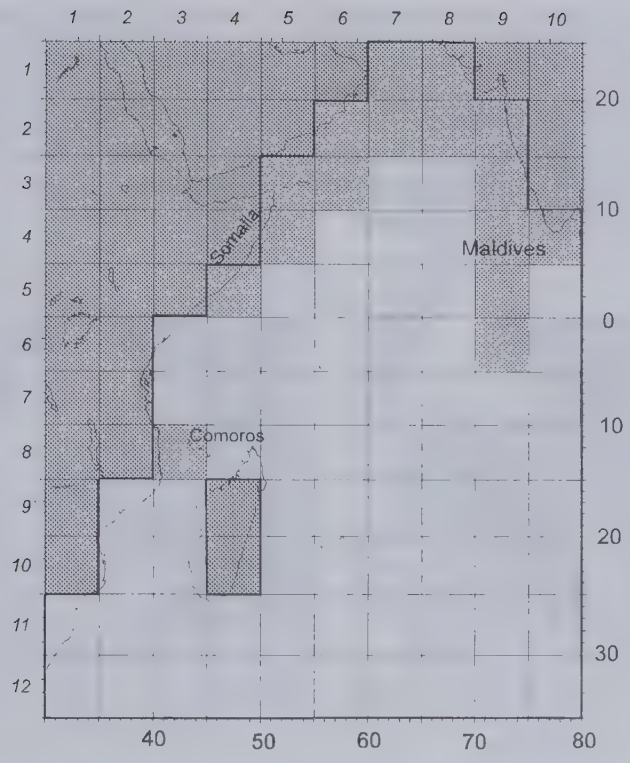

Figure 2. Fishing effort distribution of the artisanal fishery used in the simulation model. Fishing effort is set to unity in each shaded square and to zero otherwise.

3.3 Natural Mortality, Tag Mortality, Tag Shedding and Non-Reporting Rate

Although an M value of 0.05 month^{-1} was used to conduct stock assessment of yellowfin tuna in the Indian Ocean during the last workshop held in Colombo, Sri Lanka, in 1991 (IPTP, 1992), we chose for our simulations a higher value of 0.1 month^{-1} for M. This value, used also in the western Pacific (J. Hampton, SPC, pers. comm.) is probably more appropriate for the size range (40-60 cm) caught during tagging experiments. Tag mortality and shedding (α) and non-reporting rates (β) ranged widely during previous tagging programmes. In this study, we took an average value of 0.9 for α and 0.6 for β. The proportion of tag recoveries reported with all relevant information was also set to 0.95.

3.4 Diffusion Coefficient

No estimations of diffusion coefficients are yet available for yellowfin in the Indian Ocean. Thus, we used our model to compile simulated recaptures by time at liberty and distance travelled and compared our predicted distributions to the actual distribution obtained after a tagging experiment conducted in the western Pacific (Hampton, pers. comm.). Using the Nelder-Mead searching algorithm again, we found the diffusion coefficient that minimised the sum of squares of differences with observations. It converged readily to a value equivalent to 0.2 cells·month^{-1} in our grid of 300x300 nm^2 ; thus 0.2 cells·month $^{-1}$ was chosen as our diffusion coefficient for the area. The predicted

data match the observed data quite well (Figure 4). However, for the plot "61-120 days at liberty" and distance travelled beyond 1000 nm, the predicted recoveries are much lower than what was observed. For recoveries made after 180 days at liberty, the model predicts a larger proportion of fish recovered in remote cells than that which was observed and a smaller proportion in cells close to the cells of release. Our model assumes a uniform distribution of fishing effort over the area. This is probably not the case in reality, as fishing effort is concentrated in some areas.

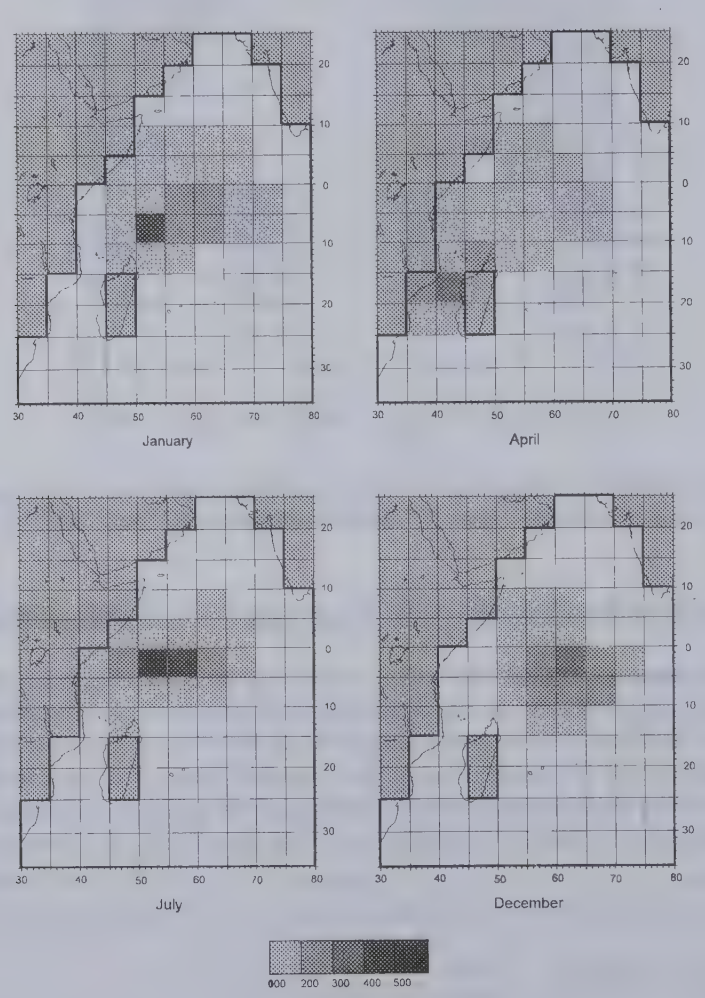

Figure 3. Distribution of purse seine fishing effort used in the simulation for the months of January, April, July and December. Fishing effort is expressed in number of days per month spent in each 5 x 5 degree square.

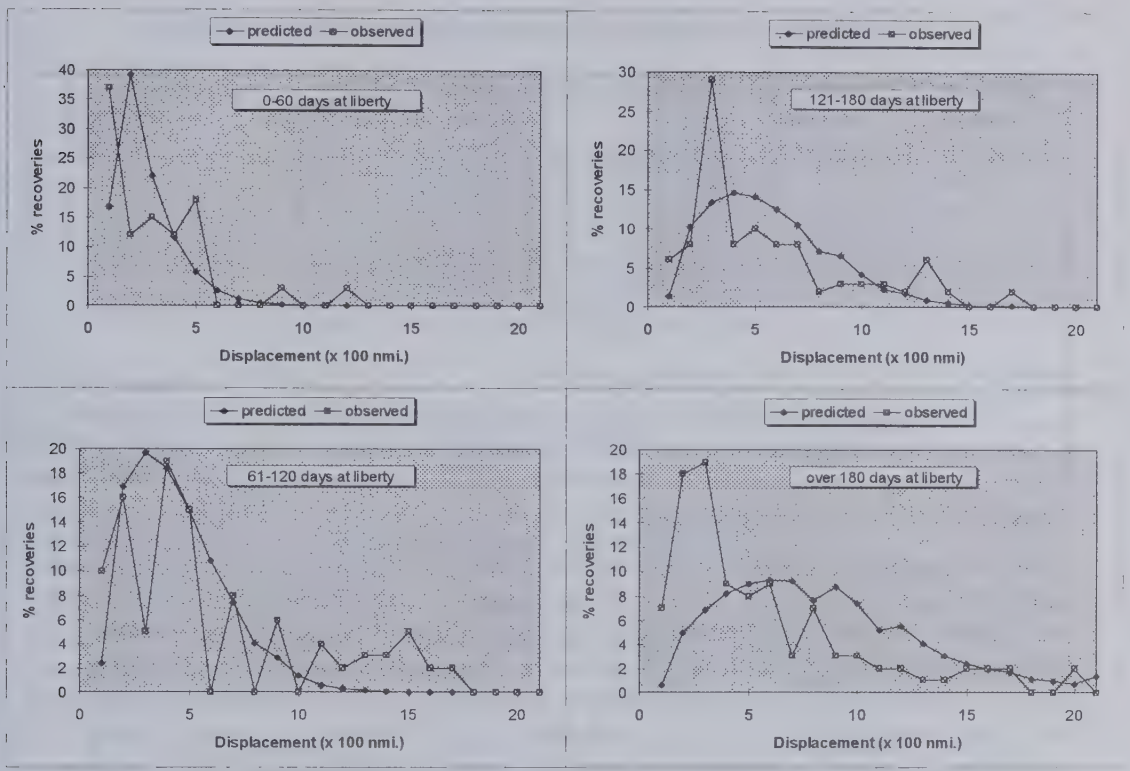

Figure 4. Observed and predicted numbers of tags recovered by distance travelled from location of release (measured in a grid of 120x120 nm). Observed tag recoveries are from tagging experiment conducted in the western Pacific (J. Hampton, SPC, pers. comm.).

3.5 Catchability, Location and Dates of Release, and Period of Recoveries

During our simulations, several scenarios of catchability levels and locations of release were tested. Parameters corresponding to each of those scenarios are summarised in Table 1. In Simulations 1, 2 and 3, only one purse seine fishery is involved, whereas in Simulations 4, 5 and 6, an artisanal fishery was added. In the experiments with one fishery, two catchability coefficients were tested, corresponding to various levels of return rate. With releases located in high F area (group of cells where the fishing mortality coefficient is high) and a catchability of 0.0008 for the purse seine fishery (Simulation 1), the average return rate is approximately equal to 15% and corresponds to our high level assumption. A value of 0.0002 (Simulation 2) led to a return rate of 5% and corresponds to our low level hypothesis. Simulation 3 combines a low catchability level with releases made in low F area and leads to a return rate of 3%. In the simulations with two fisheries (4, 5 and 6), catchability coefficients were chosen to obtain an overall recovery rate of 10%. Fish are either tagged in one fishery (Simulation 4 and 5) or in both fishery (Simulation 6).

Table 1. Values of catchability and location of releases used in simulations.

Simulation Number	Number of Fisheries in Simulation	Purse Seine Fishery		Artisanal Fishery	
		q_1	Location of Releases	q_2	Location of Releases
1	1	0.0008	high F area, 5 cruises	-	-
2	1	0.0002	high F area, 5 cruises	-	-
3	1	0.0002	low F area, 5 cruises	-	
4	2	0.0004	high F area, 5 cruises	0.015	-
5	2	0.0004	-	0.015	high F area, 5 cruises
6	2	0.0004	high F area, 3 cruises	0.015	high F area, 3 cruises

In all simulations, tagged fish are released during the first year of experiment in several months and cells of our grid. Recoveries are generated over a period of 36 months after first release. Tables 2 and 3 present the date and location of releases for each cruise when fish are released in only one fishery (purse seine or artisanal fishery). In the purse seine fishery, two schemes are tested: tagging conducted in a high F (Simulations 1, 2 and 4) or low F area (Simulation 3). In the high F area scheme, yellowfin are released west of Seychelles in January, Mozambique Channel in April, west of Seychelles again in June, north of Seychelles in August and northeast of Seychelles in December. In the low F area scheme, fish are released in the Mozambique Channel in February, southwest of Maldives in May, east of Mauritius in July and September and again in the Mozambique Channel in December. When fish are released in the artisanal fishery, tagging takes place in the northern part of the Arabian Sea in December and January and southwest of Maldives in April, June and August.

Table 2. Location of releases in the purse seiners fishery (Simulations 1 to 4).

	High F Area		Low F Area	
Cruise No	Month	Location	Month	Location
1	1	52°30'E-7°30'S	2	42°30'E-17°30'S
2	4	42°30'E-17°30'S	5	72°30'E-2°30'S
3	6	47°30'E-7°30'S	7	62°30'E-17°30'S
4	8	57°30'E-2°30'S	9	62°30'E-17°30'S
5	12	62°30'E-2°30'S	12	42°30'E-17°30'S

Table 3. Location of releases in the artisanal fishery (Simulation 5).

Cruise No	Month	Location
1	1	62°30'E-22°30'N
2	4	72°30'E-2°30'S
3	6	72°30'E-2°30'S
4	8	72°30'E-2°30'S
5	12	62°30'E-22°30'N

Table 4 gives the location of releases made in both the purse seine and artisanal fisheries. Three cruises are conducted in each fishery. In the artisanal fishery, fish are released southwest of Maldives in April and August, and in the Gulf of Oman in December. In the purse seine fishery, yellowfin are released west of Seychelles in January, in the Mozambique channel in April, and again west of Seychelles in June.

Table 4. Location of releases in both fisheries (Simulation 6).

Cruise No	Purse seine fishery		Artisanal fishery	
	Month	Location	Month	Location
1	1	52°30'E-7°30'S	4	72°30'E-2°30'S
2	4	42°30'E-17°30'S	8	72°30'E-2°30'S
3	6	47°30'E-7°30'S	12	62°30'E-22°30'N

4. PRELIMINARY RESULTS

In each simulation, 200 Monte-Carlo data sets are created. A larger number would have been preferable, but increasing the number of data sets created is very demanding on computer time, so we had to find a compromise between increasing accuracy and limiting the time that our programme was running.

CVs of the three first simulations (high and low catchability coefficient and releases made in high or low F area) are examined for each parameter to be estimated (Figure 5). Figure 5As in the results obtained by Hampton (1989), for a given number of releases, a better precision is obtained when q is high (Simulation 1). In that case, the return rate is better (around 15%) and, consequently, more information is provided for the parameter estimation. Location of releases is also an important factor affecting the precision of estimates. At constant catchability, when fish are released in a high F area, the precision of parameters is better than when the fish are released in a low F area. The precision of the catchability coefficient seems to deteriorate more than that of the other parameters when tagging occurs in a low F area. Here also, the recovery rate is the key element. In Simulation 2, the recovery rate is equal to 5%. It drops to 2% when tagged fish are released in the low F area.

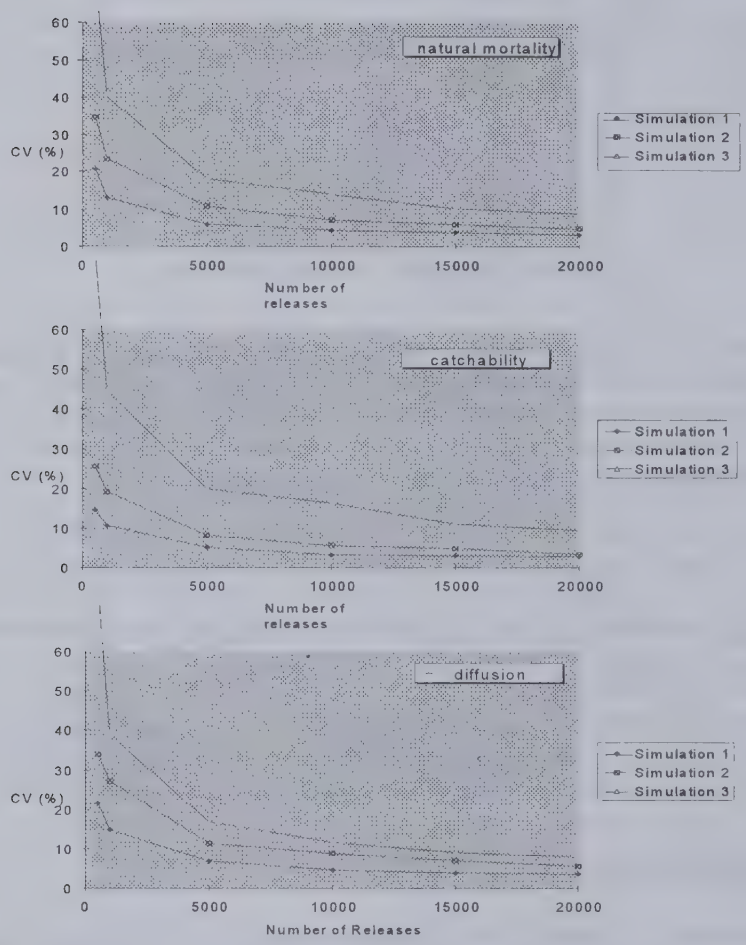

Figure 5. Coefficient of variation obtained for several levels of tagged fish released and hypotheses on catchability coefficient and location of release (see text for details on simulations). One fishery is considered. Results for each parameter are presented separately.

To obtain a precision of about 10% on all parameters with q set at 0.0002, it is necessary to tag around 10,000 fish if the fish are released in the high F area, whereas 15,000 to 20,000 fish have to be released if the tagging is carried out in a low F area. Adding another fishery to the system does not change the results concerning the precision on natural mortality and diffusion coefficients fundamentally (Figure 6). Reasonably good precision is still obtained with around 10,000 fish released and releasing fish in one or both fisheries does not affect the CVs. The results are quite different if our objective is to get good estimates of catchability. If fish are released in only one fishery, precision on the catchability coefficient of the other becomes low and it is thus necessary to tag more fish to get to the targeted precision (Simulations 4 and 5). When fish are released in the purse seine fishery, even with 20,000 fish released, the precision on artisanal fishery catchability

remains low (CV around 20%). Releasing fish in both fisheries (Simulation 6) seems to be the best alternative if our objective is to obtain good precision for all parameters simultaneously at a given level of releases.

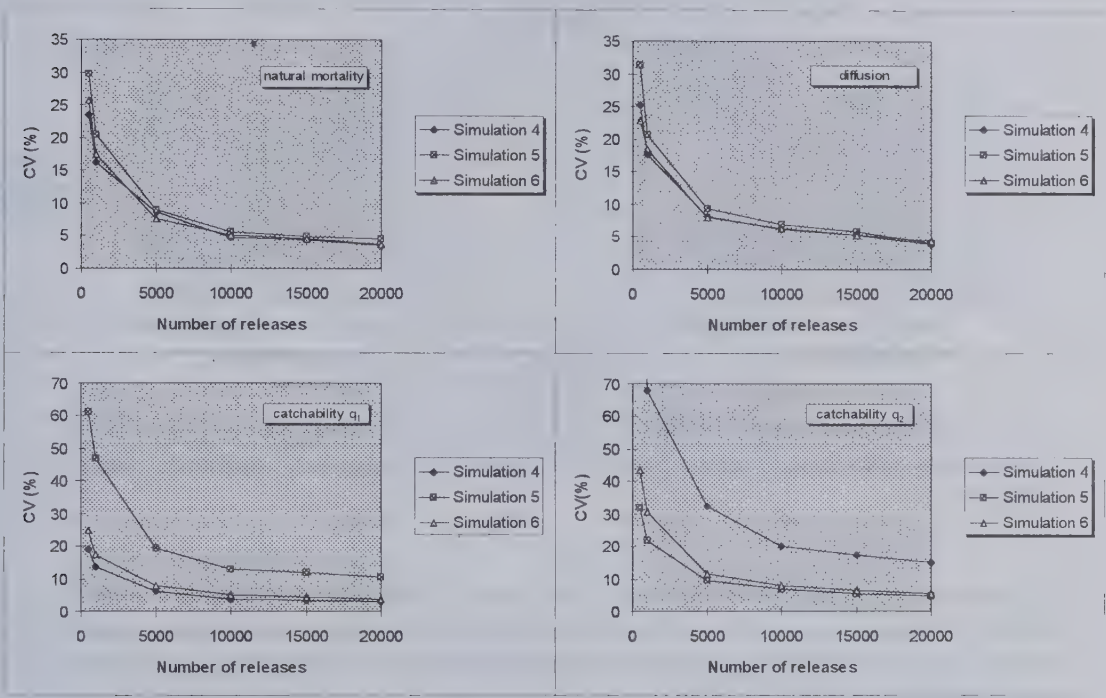

Figure 6. Coefficients of variation obtained for several levels of tagged fish releases and hypotheses on location of release (see text for details on simulations). Two fisheries are considered. Results for each parameter M, D, q_1, q_2 are presented separately.

Figure 7 shows CVs on the interaction coefficients estimated using Model II with the 200 values of $\{M, q_1, q_2, D\}$ estimated by Monte-Carlo simulation using Model I with two fisheries (Simulations 4, 5 and 6). When fish are released in one fishery, i.e., the purse seine fishery, the interaction coefficient of that fishery (affecting fishery) on the other (affected fishery), i.e., $I_{ps \rightarrow art}$ is poorly estimated. The results are similar to those obtained above on catchability coefficients. The interaction coefficient, as we defined it, and the catchability of the affected fishery when this catchability is poorly estimated, are strongly correlated and dispersion of values around the mean are large in both cases (Figure 8). This stresses the importance of estimating with good precision the catchability of the affected fishery if the tagging experiment is to be used to estimate marginal interaction coefficients. In our two-fishery system, if we want to estimate with good precision the marginal interaction of the purse seine fishery on the artisanal fishery, it is necessary to tag enough fish in the artisanal fishery.

Up to now, several "external" parameters, such as the reporting rate β, tag shedding and mortality or fishing effort, were assumed constant during the fitting procedure. In fact, those parameters are also estimated (during previous experiments or data collection)

and their estimates can be considered as a perturbation of the unknown true value of the parameter. During the fitting procedure of each simulation, instead of assuming that the parameters are constant, their values can be drawn from an appropriate distribution centred around their estimated or *a priori* values.

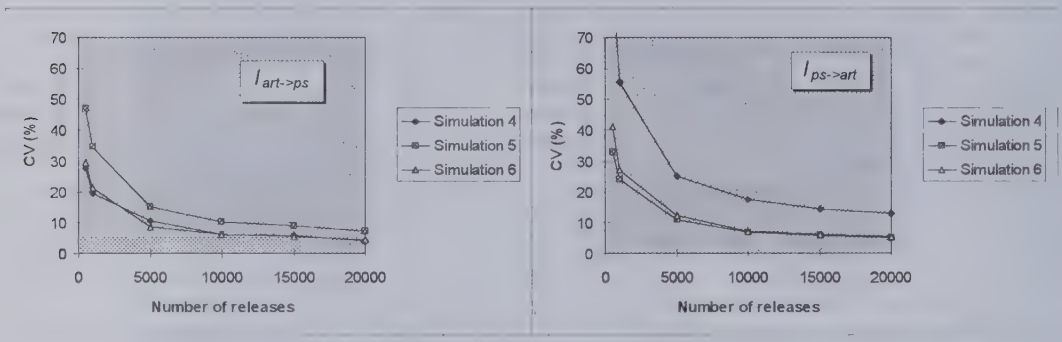

Figure 7. Coefficients of variation obtained for several levels of tagged fish release and hypotheses on location of release (see text for details on simulations), using model with two fisheries.

We tested the impact of random values of β drawn from a *beta distribution* with CV=0.1. This choice is arbitrary but the distribution presents the advantage of having limits of zero and one (Hampton, 1992). The results are presented in Figure 9. Adding uncertainty in the reporting rate has a strong effect on the precision of the catchability coefficient. The number of recoveries made in each cell at each time step, which influences the estimates of q, are clearly dependent on the level of β. For the other parameters, i.e., D and M, the effect of variability added to the reporting rate is less important and becomes negligible in the case of the diffusion rate. For this latter parameter, this is the distance covered by the tagged fish, which is important. The number of fish recovered per cell plays a minor role. The fact that β is assumed to be constant in time and space once it has been drawn from its distribution is also important in this respect; the relative distribution of tagged fish in space remains constant whatever values of reporting rate are chosen.

5. DISCUSSION

Results indicating that the precision of the parameters is strongly related to the recovery rate, and that it is better to tag fish in the high F areas, are not surprising and are very similar to those obtained by Hampton (1989) with his spatially-aggregated model. The incorporation of a spatial dimension and movements to the simulation model permits addressing situations where potential interactions can exist between geographically-separated fisheries. More surprisingly, tagging a sufficient number of fish in the affected fishery seems to be important if we want to assess with sufficient precision the impact of one fishery on the other through marginal interaction coefficients.

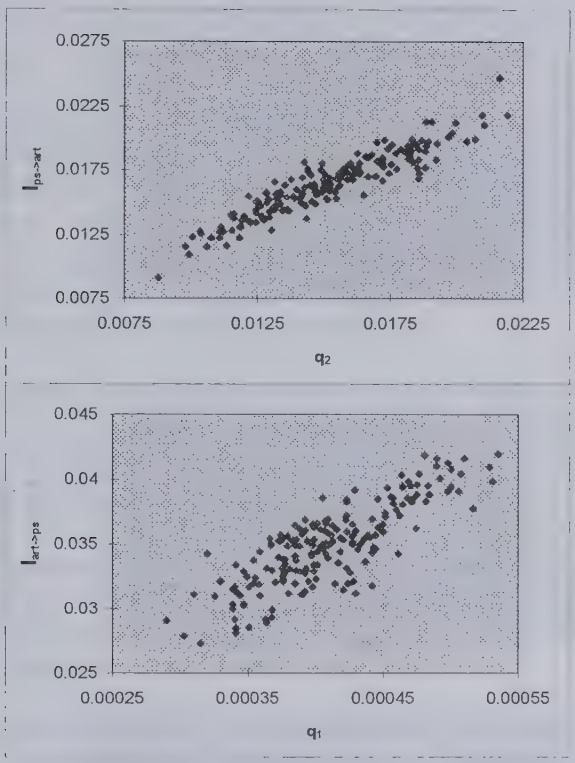

Figure 8. Estimates of interaction coefficients and catchabilities of purse seine and artisanal fishery obtained from 200 Monte-Carlo simulations with releases made in he purse seine fishery (a) or in the artisanal fishery (b). Simulations with 10,000 released yellowfin were used in both cases.

Further development of the model is required. One limitation of the analysis conducted here is the simplicity of the spatial model and its limited degree of resolution. Fish movements are described only by constant diffusion for all the area, whereas more directed movement must exist. If the fish are moving preferentially from one fishery to the other, this must have consequences on the interaction issue which we cannot assess with our current model. Adding advective movement to the model might help. It will however increase problems related to the choice of timing and direction of movement. It would be easy to adjust the model to a finer grid, e.g., 1x1 degree squares. This would, however, increase the computer time; on our 80486 (33 MHz) PC, the programme already needs up to 48 hr to estimate CVs on parameters associated with six different levels of number of tagged fish (500 to 20,000). Another limitation of the model (linked to the previous one) is the fact that the population of fish is assumed to be equally distributed in the area. A more realistic scheme would be to have fish concentrating in some areas.

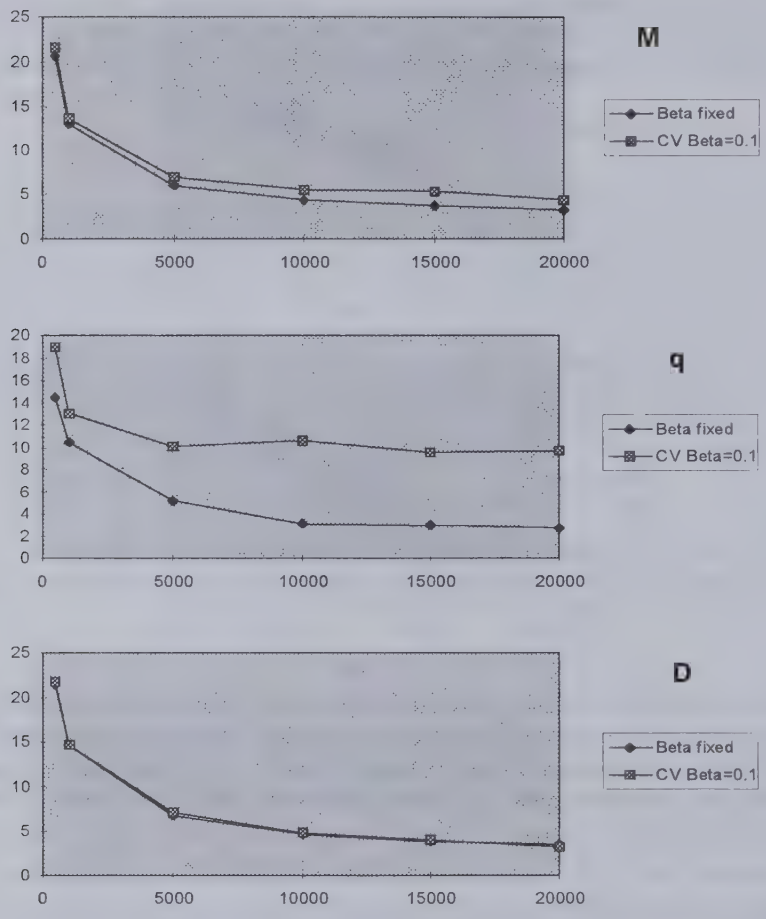

Figure 9. Coefficients of variation obtained for several levels of tagged fish release. Reporting rate is either fixed or drawn from a *beta distribution* with CV=0.1 (see text for details on simulations).

Model II (two fisheries model) also represents an important simplification of reality. Recruitment is supposed to occur constantly over time and is uniformly distributed in space, whereas some variable pattern must exist. During the estimation of the interaction coefficients, the scaling of recruitment was done only once, using average values for the parameters $\{M, q_1, q_2, D\}$. A more rigorous approach would have been to estimate a recruitment level for each set of parameters.

In his analysis with two fisheries, Hampton (1989) found that with a high exchange rate between fisheries, it is necessary to tag more fish (up to 15,000 to 20,000 in each fishery) to achieve the targeted CVs of 10%. We tried some simulations with different values of diffusion, but did not observe the same results; the impact of diffusion rate was found to be low. We did not try with very high values of D; further efforts in that direction may be

interesting. More generally, testing the robustness of the simulations to the violation of some of our assumptions would be necessary.

The estimated confidence intervals correspond to minimum values. The Monte-Carlo procedure used in simulations accounts for variations that can occur in the data sets due to various reasons, but depends on the assumption that the model describing the dynamics of tagged fish is appropriate. We have seen that adding randomness to the reporting rate can have a strong impact on the precision of the catchability coefficient estimated by Model I. It could, thus, be worthwhile to do the same with the fishing efforts which are also estimations and therefore have some random components.

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FORMULATION OF MODEL FOR STUDYING INTERACTIONS OF YELLOWFIN TUNA FISHERIES IN THE WESTERN PACIFIC

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ABSTRACT

The proposed development of an assessment model for yellowfin is described. It is anticipated that in addition to size (or age) structure the model will incorporate spatial structure. It will therefore deal with fish movement. The model should prove to be useful in addressing various questions of interaction between yellowfin fisheries in the western Pacific.

1. INTRODUCTION

Following a suggestion from the second meeting of the Western Pacific Yellowfin Tuna Research Group (WPYRG) in July, 1992, a small group of scientists has been working to develop an integrated yellowfin assessment model. A workshop was held in November, 1993 to formulate a design for such a model (Kleiber, 1994), and a proposal has subsequently been prepared seeking funds to implement the model (Anonymous, 1994). The objective of the proposed model is to address several questions posed by WPYRG and related to the status of the yellowfin population in the central and western Pacific and to the impact of the various fisheries engaged in harvesting yellowfin in that region. Some of those questions have to do with the degree to which yellowfin fisheries in the region affect each other by possible local or widespread depletion of yellowfin abundance --- in other words, fishery interaction. Two interactions of particular interest are the possible effect of the developing surface fisheries on the established longline fishery and the possibility that high seas commercial fisheries could cause local depletion that would affect small-scale coastal fisheries.

Given that the proposed model is still in early stages of development, this presentation is perforce speculative. The aim is simply to give a brief outline of the structure of the proposed model and then to point out how the model could be used to investigate fishery interaction.

2. THE MODEL

In conducting a stock assessment or a fishery interaction assessment, a significant aspect of yellowfin populations and their fisheries is that yellowfin grow during the part of their lifetime when they are exposed to fishing. As the fish grow, their vulnerability to different fishing fleets changes in different ways. It is necessary to take this variability into account by including size (or age) structure in the assessment model.

Another feature of yellowfin is that they move, sometimes over long distances. The pattern of their movement is not well understood, and its significance with respect to fishery interaction is unknown, but the potential exists for fisheries to interact when they are separated in space as well as when they are located in the same region. To evaluate that significance, the model needs to incorporate movement within and among the WPYRG statistical areas (Figure 1).

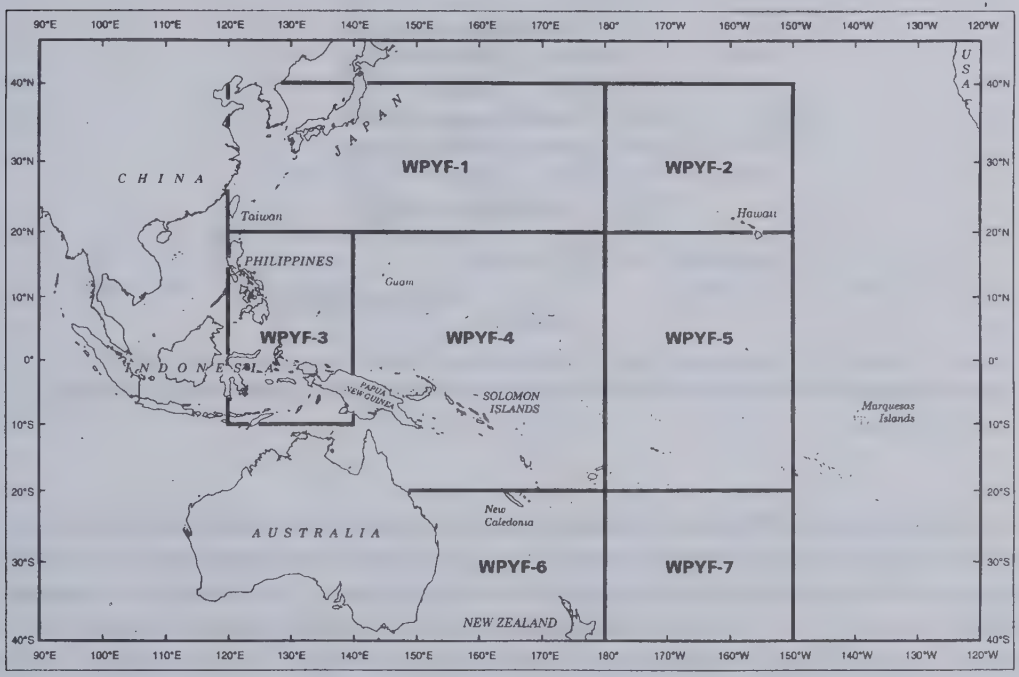

Figure 1. WPYRG study area and statistical subdivisions.

To deal with size (or age) structure, a state-of-the-art model has been developed and applied to south Pacific albacore tuna (Fournier and Sibert, 1993). That model, South Pacific Albacore Research Catch-at-Length Estimator, or SPARCLE, predicts catch by size class and time interval for a number of different fisheries. A simplified schematic picture of the model is given in Figure 2. Recruitment, which varies over time, feeds the smallest size class, and subsequent graduation to larger size classes is governed by von Bertalanffy growth parameters. Harvest is driven by a time series of effort for each of a number of fleets, each with a set of size-specific catchability parameters. Catchabilities are allowed to vary with time but with a smoothness constraint, that is, catchability is not allowed to change too abruptly from one time interval to the next. Natural death is determined by a mortality parameter.

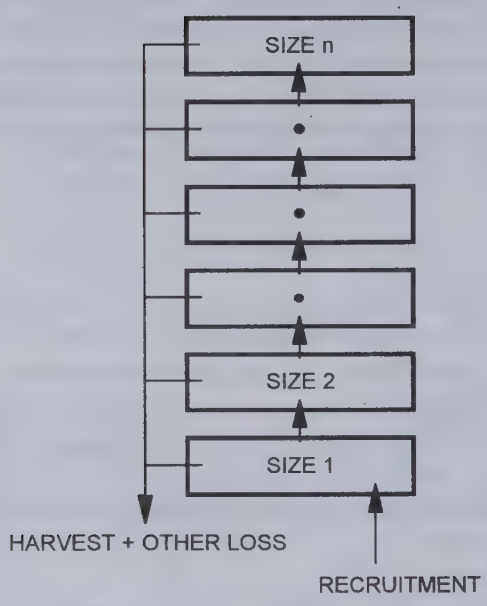

Figure 2. SPARCLE model with arrows showing recruitment to the smallest size class, growth from one size class to the next, and harvest plus other losses, such as natural mortality and emigration.

A missing feature of SPARCLE is that it does not have spatial structure and therefore does not deal with fish movement. Spatial structure can be incorporated implicitly by assigning vessels operating in different areas to different fleets. To handle fish movement explicitly, a new model, RASCLE (Regionalised, Age Structured, Catch-at-Length Estimator), is envisioned consisting of a system of multiple SPARCLEs, running in parallel (Figure 3) with one SPARCLE in each portion of some configuration of geographic subdivisions. Fish would then be moved from one area to another according to size-specific, area-specific, and possibly season-specific transfer coefficients. In the first instance, the geographic configuration might be the WPYRG statistical areas, but other configurations and spatial resolutions might used.

3. ESTIMATING PARAMETER VALUES

SPARCLE can estimate parameters for some or all of its processes of recruitment, growth, harvest and death, depending on the availability of catch and effort data to which it can be fitted. Fitting the model to data involves iterative adjustment of the model parameters to optimize the match between model predictions and observed data. The data must have sufficient detail and contrast that the individual effects of the various parameters are manifest in the fitting procedure. If the data are not able to support the estimates, that fact will be evidenced by lack of convergence in the fitting procedure or by wide confidence regions for parameter estimates.

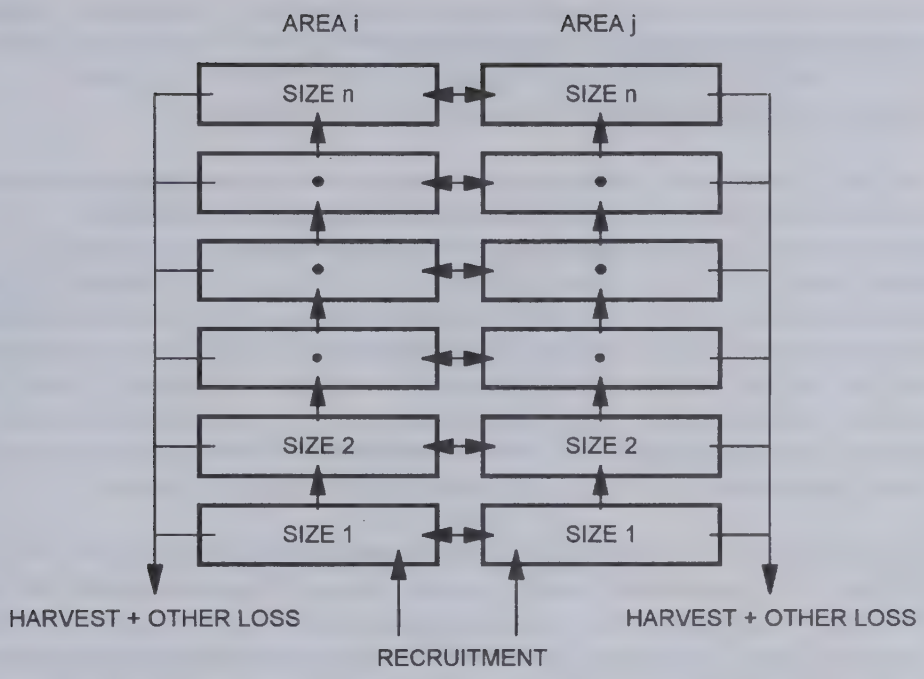

Figure 3. RASCLE model composed of multiple SPARCLEs connected by arrows depicting movement.

To estimate its parameter values, RASCLE will be fit to data in similar fashion to SPARCLE. The data will include catch and effort statistics as collected by WPYRG, that is, catch-at-size and effort by gear, time and WPYRG area. Other data at different degrees of resolution in time and space may be used where available.

A difficulty anticipated in fitting RASCLE to data is the multiplicity of parameters, with transfer coefficients added to the already parameter-rich SPARCLE. A tactic for addressing this difficulty is to experiment with various constraints on the parameters which could reduce the dimensions of the parameter space. For example, smoothness constraints could be put on the relationship of movement parameters with size or with season. Another tactic is to include other types of data. Tag displacement data from the tagging program recently conducted by the South Pacific Commission probably constitute the most powerful source of information for estimating values for the transfer coefficients. RASCLE may be adapted to utilize these data as well as catch data, or a separate movement model may be utilized to estimate transfer coefficients from tag data.

The variety of interaction questions introduces a complication in that the questions deal with various geographic scales. The surface versus longline question is on a large scale for which the broad WPYRG areas might be appropriate. However, the local depletion question will probably involve movement on a finer geographic scale. Therefore, it may be necessary to implement RASCLE or something like RASCLE, at finer degrees of spatial resolution than the WPYRG areas. In doing so, attention must be paid to the fact that movement parameters, such as transfer coefficients, cannot simply be scaled down from

one spatial scale to another and also the fact that at smaller scales, local effects, such as the influence of islands and FADs may come into play.

4. FISHERY INTERACTION

After the difficult task of obtaining a reasonable set of parameter estimates either from exogenous sources or from fitting the model to data, the relatively easy task of investigating fishery interaction can begin. At this point the model will be run in a simulation mode rather than a data fitting mode. It will simply make predictions of catch by gear, time and area from a given set of parameter values and a given pattern of effort deployment by gear, time and area. For the interaction investigation, it is not necessary for the model to duplicate a precise history of catch in the yellowfin fisheries. It is sufficient for the model to make plausible predictions of catch based on a nominal (or base case) pattern of effort by gear, season and area. The nominal effort pattern should be a typical, or average, deployment of fleets, not necessarily an actual, historical pattern.

The strengths of various interactions can be judged by re-running the model with the effort of one of the fleets altered from the nominal pattern. The predicted catch for each fleet under the altered effort pattern is then compared with the nominal results. Thus if one fleet increases its catch, the cost to other fleets in terms of diminished catch is predicted. Alternatively, if one fleet diminishes its catch, the benefit to the other fleets can be weighed against the sacrifice of the one fleet.

5. CONCLUSION

The model development described here is aimed at a variety of fishery assessment questions among which are questions of fishery interaction. The difficult part of the exercise is in implementing the model, not in assessing interaction once the model is in hand. Several obstacles lie ahead of which dealing with age-specific movement behaviour at various spatial scales probably constitutes the biggest challenge.

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INTERACTION BETWEEN SMALL-SCALE FISHERIES IN KIRIBATI AND THE INDUSTRIAL PURSE SEINE FISHERY IN THE WESTERN AND CENTRAL PACIFIC OCEAN

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ABSTRACT

The Gilbert Islands of the Republic of Kiribati straddle the equator at 173°–177°E, and are located towards the eastern extreme of the tropical tuna fishery in the western and central Pacific Ocean. Industrial purse seine vessels are licensed to fish in this area, and catches have increased substantially over the past three years. Domestic pole-and-line vessels and artisanal fishermen also target tuna in the vicinity of the Gilbert Islands. The recent increase in purse seine catches and reported declines in pole-and-line and artisanal catches have led to concerns that purse seining is reducing the supply of tuna available for capture by local fishermen.

Correlation analyses of yellowfin catch rates by artisanal troll fishermen, as determined from landing surveys, and industrial purse seine catches at various distances from and times prior to the surveys suggest that the correlations are generally weak. Over large areas, e.g., within radii of 300-600 nm of the islands, artisanal catch rates and purse seine catches are generally positively correlated, suggesting that, on this scale, variations in the abundance or catchability of yellowfin affect both purse seiners and artisanal catches in the same way. However, some negative correlations were found for smaller area (<60 nm) and time scales, indicating that localised effects may occur. Such negative correlations were detected during 1991-93 but not during 1985-90. The possible influence of El Niño conditions on these observations is discussed.

Analyses of tagging data were carried out to estimate the average impact of purse seine fishing on Kiribati pole-and-line and artisanal catch rates. A spatially aggregated model for the Gilbert Islands area indicated only a modest overall impact of local purse seine catches on pole-and-line and artisanal catch rates. A regional model with 1° square spatial structure indicated a slightly higher overall impact of the regional purse seine fishery on skipjack catches by the Kiribati pole-and-line fishery. The results of the correlation and tagging data analyses suggest that adverse impacts of purse seine fishing on artisanal and pole-and-line catches in the Gilbert Islands are more likely to occur at a small scale (1° square or

less) due to local concentrations of purse seine effort, rather than at a regional scale or on a scale of tens of degrees.

1. INTRODUCTION

The Republic of Kiribati is comprised of three groups of islands, the Gilbert, Phoenix, and Line Islands. The 33 atolls have a total land mass of only 825 km^2, but the exclusive economic zone (EEZ) is discontinuous across 3,200 km of the equatorial Pacific and occupies an area of 3,550,000 km^2 (Figure 1). This report analyses interaction issues that concern the pole-and-line and artisanal fishing operations that occur primarily in the Gilbert Islands, therefore this portion of the Kiribati EEZ is the focus of the study.

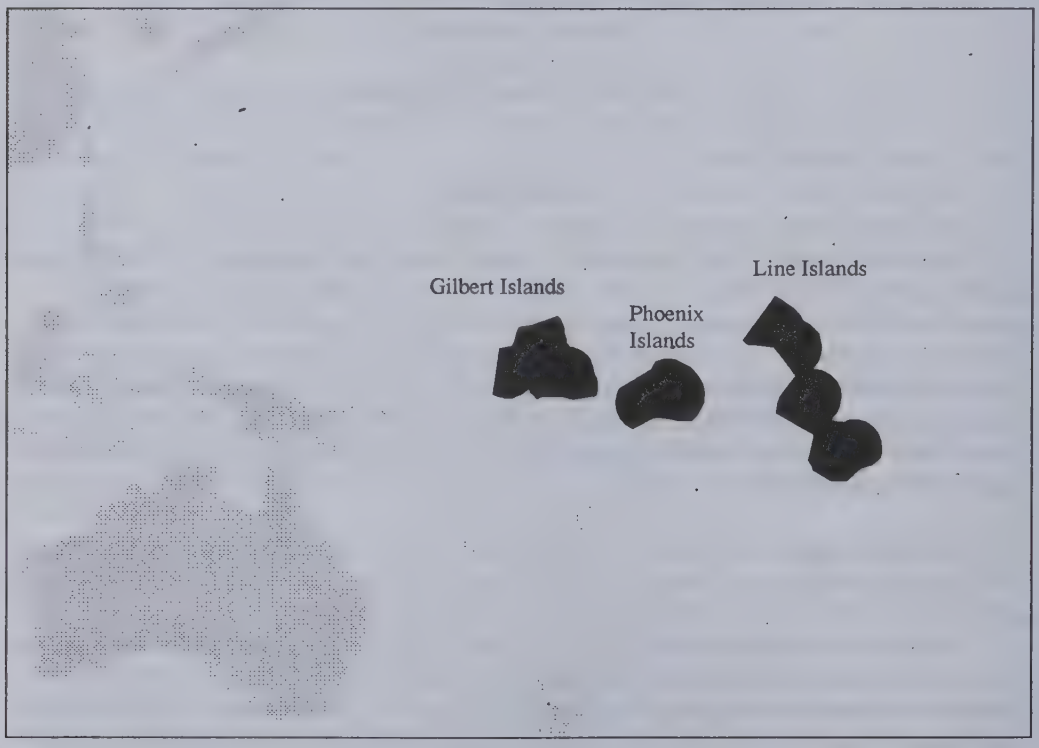

Figure 1. Map of the western Pacific Ocean, showing the Kiribati EEZ (black).

The Gilbert Islands are a group of 15 atolls that extend approximately NNW to SSE across the equator at 173°–177°E (Figure 2). The marine environment in this area is strongly influenced by the major equatorial current systems, particularly the westward-flowing South Equatorial Current and the eastward-flowing equatorial undercurrent. The equatorial upwelling, a result of the interaction of the equatorial current and easterly trade winds, frequently occurs in the vicinity of the Gilbert Islands. The upwelling brings to the surface nutrient-rich water, which provides suitable conditions for high primary and secondary production. These conditions are thought to provide the forage base for the large stocks of tuna that occur throughout the western tropical Pacific.

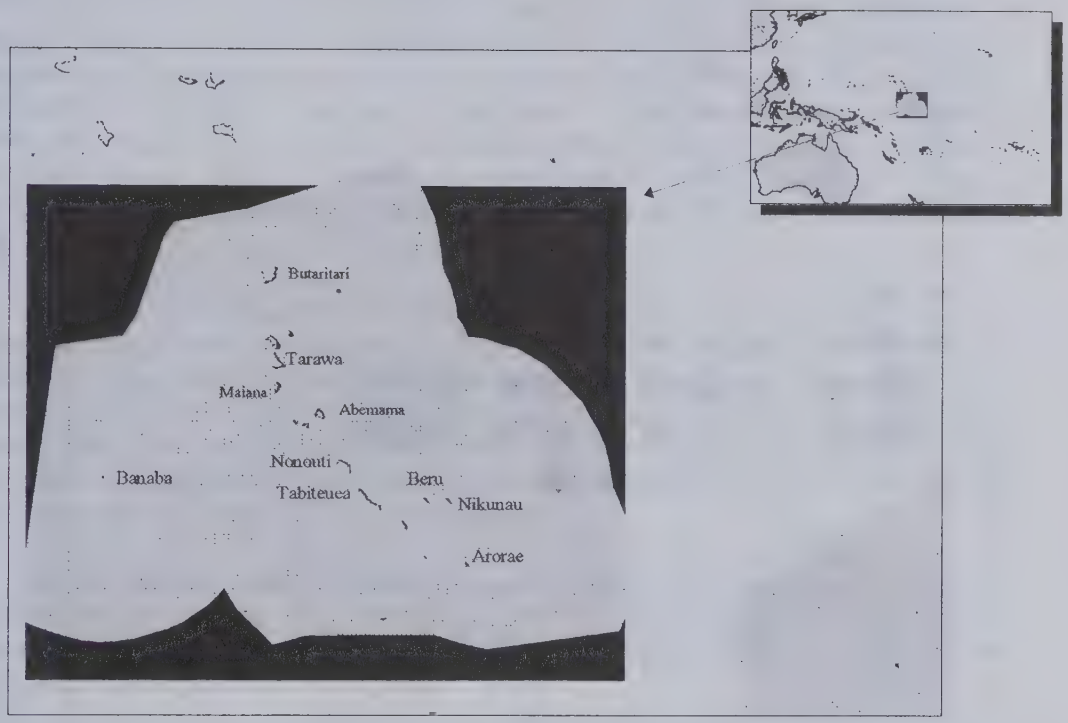

Figure 2. Map of the Gilbert Group framed by 5°N-5°S, 168°E-180°.

The western and central Pacific Ocean (WCPO), extending from the Philippines and eastern Indonesia to about 150°W, now provides in excess of 50% of world tuna production. Catches peaked at more than 1.4 million mt in 1991 and have exceeded 1 million mt since 1989 (Lawson, 1994). Most of the catch is comprised of skipjack (*Katsuwonus pelamis*) and yellowfin (*Thunnus albacares*), with smaller amounts of bigeye (*T. obesus*) and albacore (*T. alalunga*) also taken. The major gear type in terms of catch weight is purse seine, which has accounted for 650,000–850,000 mt of skipjack and yellowfin since 1990. Domestic surface fisheries in the Philippines and eastern Indonesia are also substantial, collectively landing 320,000–380,000 mt since 1990. Pole-and-line fishing has declined somewhat in recent years (140,000–200,000 mt, mainly of skipjack, since 1990), but important locally-based fleets continue to operate in Solomon Islands, Fiji and Kiribati. Longline fishing, targeting mainly bigeye and yellowfin for the valuable sashimi market, continues to generate annual catches in the vicinity of 100,000 mt.

The Gilbert Islands lie towards the eastern extreme of this activity, where average production is somewhat less than in the area north of Papua New Guinea and in the Philippines/eastern Indonesia areas (Figure 3). Nevertheless, Kiribati has been an important fishing area for some purse seine fleets in recent years, as the fishing area expanded to the east possibly in response to conditions associated with the El Niño episode that has been in evidence in the WCPO since 1991.

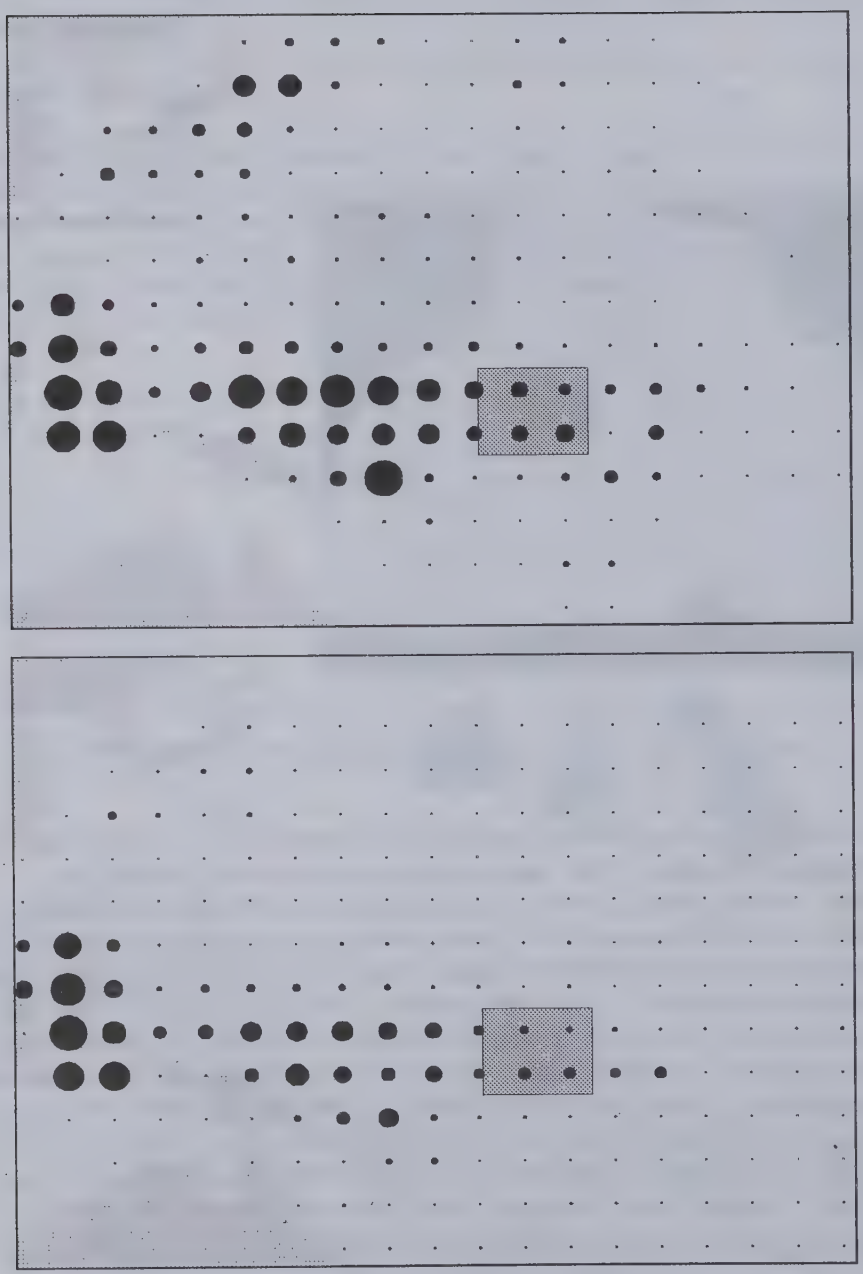

Figure 3. Distribution of skipjack (top) and yellowfin (bottom) average catch in the western Pacific Ocean, 1988–92. The maximum circle size represents annual catches of 39,200 mt for skipjack and 26,000 mt for yellowfin. The rectangle indicates the Gilbert Islands area.

Tuna fishing in the vicinity of the Gilbert Islands is carried out at several levels, with skipjack and yellowfin being the main target species in all cases. An artisanal fishery,

employing a range of gear types and operating in close proximity to the various islands, provides food, and in some cases income, to much of the local population. The total annual catch of all species from artisanal fisheries in the Gilbert Islands group, including commercial and subsistence sectors, has been estimated at 11,500 mt (Mees et al., 1988). The species composition varies with the area fished, which includes lagoons, reefs, and ocean, and the gear type, which includes various types of hook-and-line, nets, and traps, but tuna, primarily yellowfin, are the most common species caught. Landing surveys indicate that yellowfin account for 65% of the catch by troll lines and 60% of the catch by drop stone lining.

Estimates of total artisanal tuna catches in the Gilbert Islands are not available. However, there is some evidence that the artisanal tuna catch has declined since 1990. Since 1987, the government-owned fishing company, Te Mautari Ltd (TML), has purchased tuna which the artisanal fishermen based on Tarawa could not otherwise market or consume. From 1988 to 1990, the amount of tuna sold to TML averaged about 175 mt per annum. The amount dropped to less than 20 mt per annum in 1991 and 1992, and in 1993, less than one metric ton was sold to TML.

TML has operated a fleet of small Japanese-style pole-and-line vessels since 1981. Up to six vessels have fished, occasionally in Fiji and Solomon Island waters as well as in the Gilbert Islands. The catch of skipjack and yellowfin peaked at 2,300 mt in 1989, but has declined in recent years (293 mt in 1993).

The Government of Kiribati also licenses distant-water fishing nation (DWFN) fleets to fish in its waters. Japanese pole-and-line and longline fleets have been licensed to fish in the EEZ since 1978. Pole-and-line fishing has been sporadic, with catches in the vicinity of the Gilbert Islands exceeding 20,000 mt in only a few years. Longlining has generated yellowfin and bigeye catches of the order of several thousand mt per year. Purse seine fishing by various fleets occurred in the Gilbert Island area during the 1980s, generally recording annual catches of less than 10,000 mt. However, since 1990, purse seine catches, mainly by USA vessels, have increased dramatically, reaching approximately 120,000 mt in 1993. This trend has continued in 1994, with Korean, Japanese and Federated States of Micronesia vessels also being licensed to fish in the area.

The trends in catches in the vicinity of the Gilbert Islands, particularly the increasing purse seine catch and declining artisanal and TML pole-and-line catches since 1990, have caused concerns that fishery interaction is taking place. Specifically, the concern is that the large catches by USA and now other purse seiners (which are highly visible to the local community, as transshipment of purse seiners in Tarawa is now routine) are directly reducing the supply of tuna available for capture by artisanal fishermen and the TML pole-and-line fleet.

The objective of this report is to examine in detail the question of interaction between the DWFN purse seine fishery and domestic fishing activities in the Gilbert Islands. We first use simple regression models, in which artisanal troll CPUE for yellowfin (the dominant species caught) is the dependent variable and purse seine yellowfin catch is the independent variable, to indicate possible relationships between these fisheries. We then analyse tag recapture data to parameterise two population dynamics models, the first being

a spatially-aggregated model applied to both skipjack and yellowfin in the Gilbert Islands area, and the second being a high-resolution (1° square) spatial model applied to skipjack in a large area of the WCPO. These models are used to estimate the impacts of various levels of purse seining in the WCPO generally and in the Gilbert Islands area on the performance of the Kiribati artisanal and TML pole-and-line fleets.

2. CORRELATIONS BETWEEN ARTISANAL FISHERY CATCH RATES AND PURSE SEINE CATCHES

The trends in catches and catch rates in the Gilbert Islands have led to concerns that large purse seine catches deplete the local abundance of tuna and impact the catch rates of artisanal fishermen and the TML pole-and-line fleet. These concerns have so far not been supported by any analysis of data. In this section, a series of statistical analyses are carried out to determine the correlation between purse seine catch and artisanal catch rates under various spatial and temporal stratifications. Of particular interest is whether significant negative correlations, which might be indicative of adverse impacts of purse seine catches on artisanal catch rates, exist in the data. The analysis is restricted to purse seine–artisanal correlations, as recent TML pole-and-line data of the required resolution are not yet available.

2.1 Sources of Data

From 1985 to 1987 and from 1989 to 1993, surveys of the artisanal fisheries on several islands in Kiribati were undertaken by the Fisheries Division of the Ministry of Environment and Natural Resource Development. The surveys were conducted at landing sites, usually on a weekly basis. Data on catch and effort for a variety of fishing methods were collected. Table 1 presents the total catch of skipjack and yellowfin sampled during 1985-87 and 1989-93, for those fishing methods for which skipjack and yellowfin occurred in at least one sample. Yellowfin represented 38.1% of the total catch sampled for such fishing methods, while skipjack represented 2.4%. The amount of skipjack may be slightly underestimated since some skipjack were included in the "yellowfin" catch sampled during 1992-93. Since skipjack represented only a small proportion of the catch of tuna sampled from the artisanal fisheries, only yellowfin were considered in the correlations between artisanal catch rates and purse seine catches.

Drop-stone lining and trolling accounted for 40% and 52% respectively of the yellowfin catch sampled during the surveys; yellowfin catches for other fishing methods represent only a small proportion of the catch. No yellowfin were sampled from catches by drop-stone-lining during 1985 and 1989, whereas yellowfin were sampled from troll catches for each year; therefore, only survey data for trolling were considered in the analysis. Annual skipjack and yellowfin catches sampled for trolling are given in Table 2; yellowfin represents almost two-thirds of the total troll catch.

Catches of yellowfin by purse seiners were determined from logbook data held at SPC. The logbook data, which contain the catch by species for each purse seine set, with the set position recorded to the nearest minute of latitude and longitude, were provided to SPC by coastal states in the region; the coastal states collected the data either from distant-water purse-seine fleets under access agreements or from domestic fleets. Coverage of catches by the purse-seine fleets

of South Korea and Taiwan by logbook data held at SPC is poor for most of the period under consideration. However, purse-seine catches in the proximity of the Gilbert Islands have been taken almost entirely by the USA fleet; the Japanese and Taiwanese purse-seine fleets were not licensed to fish in the waters of Kiribati during the period under consideration, while Korean purse seiners have been licensed to fish in the waters of Kiribati only since 1993. The USA fleet has been licensed to fish in the waters of Kiribati during most of the period under consideration, from 1987 to 1988 under access agreements between the Kiribati government and certain vessel owners, and from 1988 to the present under the multilateral treaty between the USA and certain Pacific island nations. Purse seiners from the former Soviet Union were licensed to fish in the waters of Kiribati from 1985 to 1986, and purse seiners from the Federated States of Micronesia (FSM) have been licensed since 1991; coverage by logbook data of catches by the Soviet fleet are poor, although catches are considered to have been low, while coverage of catches by the FSM fleet is high.

Table 1. Skipjack (SKJ), yellowfin (YFT) and total catches (kg) sampled by Kiribati artisanal landings surveys during 1985-87 and 1989-93. Only fishing methods for which skipjack and yellowfin were sampled are included.

Fishing method	SKJ	%	YFT	%	Total
Hand nets	-	-	18.0	0.5	3867.4
Fixed gillnets	-	-	5.1	0.0	11138.9
Drift gillnets	-	-	19.0	0.2	11228.6
Gillnets unspecified	-	-	40.0	0.9	4400.2
Handlines	128.2	1.0	1788.5	14.3	12527.3
Tuna pole-and-line	321.3	19.8	371.6	22.9	1623.4
Vertical longline	34.5	0.3	1850.7	14.8	12510.3
Drop stone lining	1071.2	3.1	20636.2	59.9	34473.3
Drift longlines	-	-	128.0	24.3	526.0
Trolllines	1717.5	4.1	26787.2	64.6	41457.0
Hook and line unspecified	20.0	1.3	133.2	8.4	1586.9
Unspecified	30.0	3.5	52.6	6.2	850.6
Total	3322.7	2.4	51830.1	38.1	136189.9

2.2 Method

Correlations between yellowfin catch rates in the troll fishery and purse seine catches of yellowfin were determined as follows. The dependent variable in the linear regression was the troll catch rate determined by aggregating catch and effort data for individual trips by island and week; the aggregation resulted in 240 island-week strata based on data for 916 fishing trips. The independent variable associated with each stratum was the amount of yellowfin caught by purse seiners within a specified distance from the island and within a specified time period prior to the week surveyed. Correlations were determined for distances of 60, 120, 180, 300 and 600

nautical miles from the island surveyed; for each distance from the island, correlations were determined for time periods of 2, 4, 8, 12 and 24 weeks prior to the week surveyed.

Table 2. Annual skipjack (SKJ), yellowfin (YFT) and total catches (all in kg) by troll lines sampled by Kiribati artisanal landings surveys.

Year	SKJ	%	YFT	%	Total
1985	137.0	31.1	205.0	46.6	440.0
1986	67.5	3.2	1,047.7	50.3	2,084.4
1987	138.4	5.6	1,743.8	70.6	2,469.3
1988	—	—	—	—	—
1989	—	—	2,359.2	98.4	2,397.3
1990	1,242.1	7.2	9,411.0	54.4	17,305.8
1991	132.5	3.7	178.0	5.0	3,573.4
1992	—	—	5,906.2	88.8	6,649.0
1993	—	—	5,936.3	90.8	6,537.8
Total	1,717.5	4.1	26,787.2	64.6	41,457.0

Two definitions of troll catch rate were used to determine the dependent variable. The first was simply the average number of yellowfin caught per trip for the island-week stratum. The second was determined as follows. During the landing survey, information on the duration of each trip in hours and the number of fishermen per trip were collected. Regressions of the number of yellowfin caught per trip on (1) the number of fishermen per trip, (2) the number of hours per trip and (3) the number of man-hours per trip, for 916 trips, indicated that the number of yellowfin caught per trip was related most strongly to the number of fishermen per trip (Table 3). The number of fishermen per trip presumably determines the number of troll lines used per trip. It is possible that the number of hours per trip and the number of man-hours per trip were less strongly related to the number of yellowfin caught per trip than the number of fishermen because the number of hours per trip may have included the time in transit to and from the fishing grounds, rather than actual time spent fishing. The second definition of troll catch rate used to determine the dependent variable was the number of yellowfin per fisherman per trip.

Table 3. Relationships between the number of yellowfin caught per troll line trip and three measures of fishing effort. The number of trips (N), the correlation coefficient (r), the proportion of the variation in yellowfin catch per trip explained by the regression (R^2) and the F statistic are presented. The significance of the F statistic at the 0.01 level is denoted with **

Fishing effort	N	r	R^2	F
Number of men	916	0.408	0.166	182.27 **
Hours fished	916	0.017	0.000	0.27
Man-hours fished	916	0.276	0.076	75.27 **

The amount of data and average catch rates for both the troll and the purse-seine fishery are summarised by year in Table 4. For those years for which the number of strata is large, the trends in the number of yellowfin per troll trip and the number of yellowfin per fisherman are similar. The purse-seine data exhibit a high degree of contrast, with annual yellowfin catches ranging from less than 500 mt to over 30,000 mt.

Table 4. Number of strata (island-weeks), number of troll line trips, number of yellowfin caught (YFT), number of yellowfin caught per trip (CPUE 1) and number of yellowfin caught per man (CPUE 2), determined from Kiribati artisanal surveys, and the number of days fished or searched, metric tonnes of yellowfin caught (YFT) and metric tonnes of yellowfin caught per day fished or searched (CPUE) by purse seiners in the vicinity of the Gilbert Islands, determined from logbooks held at SPC.

	Kiribati landings survey : troll lines					Purse seine		
Year	Strata	Trips	YFT	CPUE 1	CPUE 2	Days	YFT	CPUE
1985	4	8	29	3.63	1.12	16	35	2.19
1986	24	69	186	2.70	1.26	—	—	—
1987	29	74	276	3.73	1.73	268	2.807	10.47
1988	—	—	—	—	—	136	548	4.03
1989	2	59	270	4.58	2.76	166	365	2.20
1990	122	319	1,410	4.42	2.23	2,150	22,785	10.60
1991	7	50	38	0.76	0.20	864	1,112	1.29
1992	13	162	2,259	13.94	5.10	2,100	10,956	5.22
1993	39	175	1,544	8.82	4.15	4,701	31,926	6.79
Total	240	916	6,012	6.56	2.90	10,401	70,536	6.78

2.3 Results and Discussion

Table 5 presents the results of correlations between the number of yellowfin caught per troll trip and purse-seine catches of yellowfin. For purse-seine catches within 60 nm, the correlations are negative; however, the amount of variation in troll catch rates explained by the regression is low and the regressions are not statistically significant. For a distance of 180 nm and time periods of 2 and 4 weeks, the correlations are positive and significant; however, the positive correlations are weak. For distances of 300 nm and 600 nm, the correlations are positive and statistically significant; the positive correlations are weak to moderate. The amounts of variation explained by the regression and the values of the *F*-statistic declined with an increase in the time period for distances of 300 nm and 600 nm; the decline appears to be gradual for 300 nm and steep for 600 nm.

Table 6 presents the results of correlations between the number of yellowfin caught per fisherman per troll trip and purse-seine catches of yellowfin. The results are similar to those for correlations with the number of yellowfin per troll trip (Table 5), with non-significant negative correlations for 60 nm, and significant positive correlations for 180, 300 and 600 nm; significant positive correlations are also evident for a distance of 120 nm.

Tables 5 and 6 also present the number of strata for which the purse-seine catch of yellowfin was positive. For a distance of 60 nm and a time period of 2 weeks, only 33 out of a possible

240 strata are associated with a positive purse-seine catch. The number of strata with a positive purse-seine catch increases with distance and time, such that for a distance of 600 nm and a time period of 24 weeks, 231 out of 240 strata are associated with a positive purse-seine catch. Thus for relatively short distances and time periods, the results are weighted towards strata with zero purse-seine catch.

Table 5. Correlations between yellowfin catch rates (number of fish per trip) by troll lines, determined from Kiribati artisanal landing surveys, and yellowfin catches by purse seiners, determined from logbooks held at SPC. The number of strata (island-weeks) for which the purse seine catch was positive (N^+) and the correlation coefficient (r) are given for regressions of troll catch rates for 240 island-week combinations on purse seine catches within various distances (nm) from the island surveyed and time periods (weeks) prior to the landing survey. Statistical significance at the 0.05 level is noted with *; significance at the 0.01 level is noted with **.

Distance	Time	N^+	r	
60	2	33	-0.076	
60	4	54	-0.066	
60	8	72	-0.059	
60	12	82	-0.071	
60	24	122	-0.093	
120	2	69	0.124	
120	4	94	0.109	
120	8	117	0.010	
120	12	136	-0.008	
120	24	173	0.040	
180	2	101	0.134	*
180	4	134	0.140	*
180	8	163	0.056	
180	12	180	0.060	
180	24	192	0.102	
300	2	148	0.296	**
300	4	169	0.329	**
300	8	189	0.272	**
300	12	195	0.281	**
300	24	201	0.220	**
600	2	193	0.270	**
600	4	204	0.255	**
600	8	216	0.178	**
600	12	218	0.175	**
600	24	231	0.128	*

Table 6. Correlations between yellowfin catch rates (number of fish per man) by troll lines, determined from Kiribati artisanal landing surveys, and yellowfin catches by purse seiners, determined from logbooks held at SPC. See caption for Table 5.

Distance	Time	N^+	r	
60	2	33	-0.048	
60	4	54	-0.035	
60	8	72	-0.017	
60	12	82	-0.035	
60	24	122	-0.080	
120	2	69	0.198	**
120	4	94	0.158	*
120	8	117	0.040	
120	12	136	0.020	
120	24	173	0.031	
180	2	101	0.193	**
180	4	134	0.181	**
180	8	163	0.069	
180	12	180	0.060	
180	24	192	0.064	
300	2	148	0.317	**
300	4	169	0.309	**
300	8	189	0.240	**
300	12	195	0.236	**
300	24	201	0.156	*
600	2	193	0.268	**
600	4	204	0.224	**
600	8	216	0.150	*
600	12	218	0.143	*
600	24	231	0.088	

Table 7 presents the results of correlations between the number of yellowfin caught per troll trip and purse-seine catches of yellowfin, after excluding strata for which the purse-seine catch was zero. For distances of 300 and 600 nm, for which the number of strata with a positive purse-seine catch is high, the results are similar to those for the regressions which included zero purse-seine catches. For 60 nm, however, statistically significant weak to moderate negative correlations are evident, whereas when zero purse-seine catches are included, the negative correlations are weak and non-significant.

Table 8 presents the results of correlations between the number of yellowfin caught per fisherman per troll trip and purse-seine catches of yellowfin, after excluding strata for which the purse-seine catch was zero. Again, the results are similar to those for correlations with the number of yellowfin per troll trip, after excluding strata for which the purse-seine catch was zero (Table 7).

Table 7. Correlations between yellowfin catch rates (number of fish per trip) by troll lines, determined from Kiribati artisanal landing surveys, and yellowfin catches by purse seiners, determined from logbooks held at SPC. Replicates for which there were no purse seine catch have been excluded. See caption for Table 5.

Distance	Time	N^+	r	
60	2	33	-0.440	**
60	4	54	-0.319	*
60	8	72	-0.298	*
60	12	82	-0.238	*
60	24	122	-0.268	**
120	2	69	0.236	*
120	4	94	0.138	
120	8	117	-0.063	
120	12	136	-0.061	
120	24	173	-0.073	
180	2	101	0.100	
180	4	134	0.088	
180	8	163	0.012	
180	12	180	0.014	
180	24	192	0.035	
300	2	148	0.281	**
300	4	169	0.319	**
300	8	189	0.258	**
300	12	195	0.251	**
300	24	201	0.185	**
600	2	193	0.228	**
600	4	204	0.220	**
600	8	216	0.150	*
600	12	218	0.148	*
600	24	231	0.111	

Statistically significant negative correlations are only evident for a distance of 60 nm. In order to determine in greater detail the distances and time periods for which significant negative correlations exist, the correlations were also determined for distances of 40, 50, 60, 70 and 80 nm and time periods of 1, 2, 3, 4 and 5 weeks. The results (Tables 9 and 10) indicate that significant negative correlations are evident only for distances of 50 and 60 nm; however, the numbers of strata for a distance of 40 nm and time periods of 1 to 4 weeks are small.

In summary, when large areas, i.e., circles of 300 and 600 nm radius about an island, are considered, the correlation between the troll catch rate and the purse-seine catch is generally positive (e.g., Figure 4). If we consider that such areas are too large for local interactions to occur or to be detected, a positive correlation would be expected if the abundance of yellowfin within a large area affects the success of both trolling and purse-seining in the same manner. When fish are generally abundant in a large area, both trollers and seiners would be expected to do well; when fish are sparse, both trollers and seiners (at least those that remain in the area) would be expected to do poorly.

Table 8. Correlations between yellowfin catch rates (number of fish per man) by troll lines, determined from Kiribati artisanal landing surveys, and yellowfin catches by purse seiners, determined from logbooks held at SPC. Replicates for which there were no purse seine catch have been excluded. See caption for Table 5.

Distance	Time	N^+	r	
60	2	33	-0.402	*
60	4	54	-0.274	*
60	8	72	-0.216	
60	12	82	-0.220	*
60	24	122	-0.266	**
120	2	69	0.346	**
120	4	94	0.217	*
120	8	117	-0.012	
120	12	136	-0.020	
120	24	173	-0.058	
180	2	101	0.193	
180	4	134	0.171	*
180	8	163	0.057	
180	12	180	0.031	
180	24	192	-0.009	
300	2	148	0.340	**
300	4	169	0.329	**
300	8	189	0.229	**
300	12	195	0.205	**
300	24	201	0.112	
600	2	193	0.240	**
600	4	204	0.182	**
600	8	216	0.119	
600	12	218	0.112	
600	24	231	0.065	

When small areas, i.e., circles of 50 to 60 nm radius around an island, are considered, the correlation between the troll catch rate and the purse-seine catch is generally negative (e.g., Figure 5). However, the negative correlation is statistically significant only when strata for which the purse-seine catch is zero are excluded. When strata with zero purse seine catches are included in the analysis, the correlation is not significant, presumably because local abundance in these strata is so low that troll catch rates are also depressed. While the same type of abundance effect producing positive correlations would also be expected to occur on the smaller scale, the negative correlations could have been the result of high local fishing mortality by purse seiners depleting local yellowfin abundance and thus impacting artisanal troll catch rates. Presumably, this competition effect predominates over the abundance effect at small spatial and temporal scales.

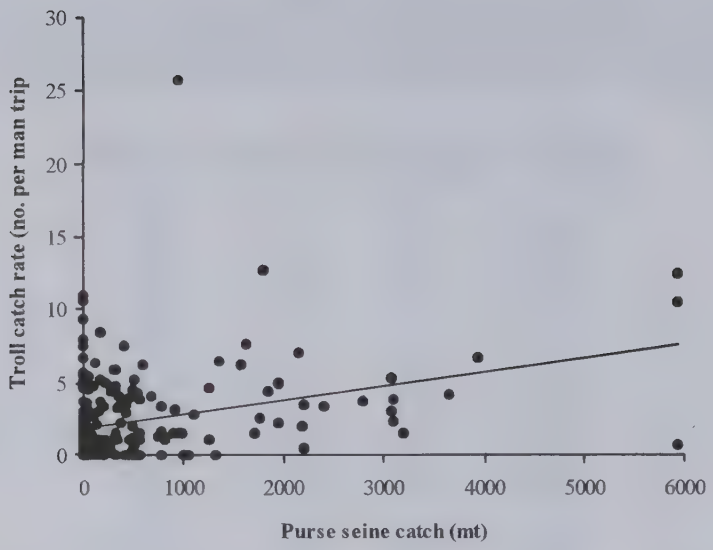

Figure 4. Regression of Kiribati troll catch rate (number of yellowfin per man per trip) on yellowfin catches by purse seiners within 300 nm of the island surveyed and two weeks prior to the week surveyed.

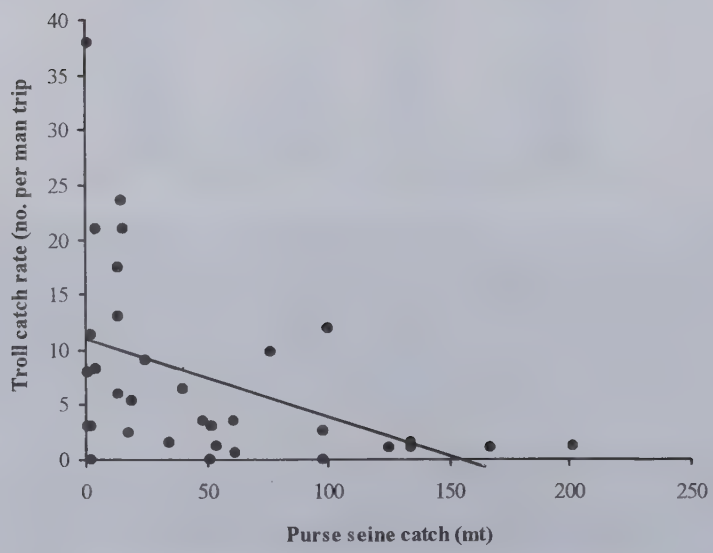

Figure 5. Regression of Kiribati troll catch rate (number of yellowfin per trip) on yellowfin catches by purse seiners within 60 nm of the island surveyed and two weeks prior to the week surveyed.

Table 9. Correlations between yellowfin catch rates (number of fish per trip) by troll lines and yellowfin catches (metric tonnes) by purse seiners. Replicates for which there were no purse seine catch have been excluded. See caption for Table 5.

Distance	Time	N^+	r	
40	1	9	-0.368	
40	2	16	-0.317	
40	3	21	-0.155	
40	4	28	-0.251	
40	5	33	-0.144	
50	1	17	-0.429	
50	2	29	-0.380	*
50	3	37	-0.274	
50	4	47	-0.389	**
50	5	53	-0.375	**
60	1	19	-0.473	*
60	2	33	-0.440	**
60	3	44	-0.226	
60	4	54	-0.319	*
60	5	60	-0.320	*
70	1	22	-0.316	
70	2	38	-0.266	
70	3	50	-0.047	
70	4	60	-0.182	
70	5	66	-0.174	
80	1	25	-0.181	
80	2	45	-0.072	
80	3	57	-0.017	
80	4	70	-0.133	
80	5	77	-0.135	

Negative correlations on small spatial and temporal scales are not a consistent feature throughout the entire time series. For the period 1985-90, the negative correlations are generally small and not statistically significant (Table 11). On the other hand, for the period 1991-93, the negative correlations are stronger and highly significant for temporal scales of up to 8 months (Table 12). Different environmental conditions characterised these two periods – during 1991-93, El Niño conditions persisted over much of the WCPO, while the earlier period was a mix of normal conditions, a weak El Niño in 1986-87 and a La Niña (anti- El Niño) in 1988.

There are two hypotheses, both related to El Niño, that might explain the stronger negative correlations, and by implication, greater purse seine–artisanal interaction, in recent years. First, the distribution of purse seine effort was somewhat displaced to the east in 1991-93. This shift in effort, primarily by USA purse seiners, might have been encouraged by a higher catchability of skipjack and yellowfin due to the shallower thermocline that is typical of El Niño conditions in the WCPO, and a preference by skippers to operate close to their unloading port (Pago Pago)

when fishing conditions in this area are good. The easterly concentration of effort may then have resulted in higher exploitation rates in the Gilbert Islands area and therefore increased the potential for interaction with the domestic fisheries.

Table 10. Correlations between yellowfin catch rates (number of fish per man) by troll lines and yellowfin catches (metric tonnes) by purse seiners. Replicates for which there were no corresponding purse seine catch have been excluded. See caption for Table 5.

Distance	Time	N^+	r	
40	1	9	-0.332	
40	2	16	-0.295	
40	3	21	-0.127	
40	4	28	-0.240	
40	5	33	-0.126	
50	1	17	-0.451	
50	2	29	-0.369	*
50	3	37	-0.274	
50	4	47	-0.413	**
50	5	53	-0.390	**
60	1	19	-0.438	
60	2	33	-0.402	*
60	3	44	-0.143	
60	4	54	-0.274	*
60	5	60	-0.277	*
70	1	22	-0.262	
70	2	38	-0.248	
70	3	50	0.039	
70	4	60	-0.103	
70	5	66	-0.113	
80	1	25	-0.150	
80	2	45	-0.102	
80	3	57	-0.009	
80	4	70	-0.101	
80	5	77	-0.121	

A second hypothesis is that productive waters near the equator between about 130°E and 165°E are pushed eastwards by stronger westerly winds and easterly setting equatorial currents during El Niño periods. If this hypothesis is correct, it is possible that tuna that generally tend to aggregate around the banks fished by Kiribati troll fishermen during non- El Niño periods are more dispersed during El Niño periods because of the more widespread availability of baitfish resulting from the easterly expansion of high primary and secondary production. While this hypothesis is untested at present, the observation of higher occurrence of the oceanic anchovy *Stolephorus punctifer* in the stomachs of skipjack and yellowfin sampled during tagging cruises in 1991 and 1992 (24% occurrence – SPC, unpublished data) compared with similar samples taken on tagging cruises in 1978 and 1979 (10% occurrence – Kleiber and Kearney, 1983) lends

some support. If the hypothesis is correct, greater mixing of tuna between the banks fished by Kiribati troll fishermen and the offshore waters fished by purse seiners might be expected during El Niño periods, which would tend to facilitate the negative interactions that have been detected for the 1991-93 period.

Either or both of these hypothesised effects of El Niño could have led to the observed patterns in the correlations. More research on the effects of El Niño on tuna catchability and movement would be required to test these hypotheses.

Table 11. Correlations between yellowfin catch rates (number of fish per trip) by troll lines during 1985-90 and yellowfin catches (metric tonnes) by purse seiners. Replicates for which there were no corresponding purse seine catch have been excluded. See caption for Table 5.

Distance	Time	N^+	r	
60	2	11	-0.252	
60	4	23	-0.229	
60	8	36	-0.161	
60	12	42	-0.255	
60	24	73	-0.255	*
120	2	33	0.347	*
120	4	51	0.212	
120	8	67	-0.047	
120	12	82	-0.049	
120	24	114	-0.038	
180	2	57	0.236	
180	4	88	0.227	*
180	8	113	0.031	
180	12	125	0.000	
180	24	133	0.112	
300	2	103	0.409	**
300	4	123	0.447	**
300	8	135	0.378	**
300	12	137	0.314	**
300	24	142	0.285	**
600	2	139	0.247	**
600	4	148	0.241	**
600	8	157	0.155	
600	12	159	0.142	
600	24	172	0.142	

Table 12. Correlations between yellowfin catch rates (number of fish per trip) by troll lines during 1991-93 and yellowfin catches (metric tonnes) by purse seiners. Replicates for which there were no corresponding purse seine catch have been excluded. See caption for Table 5.

Distance	Time	N^+	r
60	2	22	-0.564 **
60	4	31	-0.565 **
60	8	36	-0.490 **
60	12	40	-0.294
60	24	49	-0.342 *
120	2	36	-0.024
120	4	43	-0.048
120	8	50	-0.087
120	12	54	-0.062
120	24	59	-0.106
180	2	44	-0.048
180	4	46	-0.081
180	8	50	-0.022
180	12	55	0.028
180	24	59	-0.096
300	2	45	0.119
300	4	46	0.130
300	8	54	0.092
300	12	58	0.156
300	24	59	0.035
600	2	54	0.256
600	4	56	0.234
600	8	59	0.165
600	12	59	0.171
600	24	59	0.056

3. TAG-RECAPTURE MODELS

3.1 Tagging Experiments in the Western Tropical Pacific

Two major tagging experiments have been carried out in the western tropical Pacific by the South Pacific Commission – the Skipjack Survey and Assessment Programme (SSAP) and the Regional Tuna Tagging Project (RTTP). In the SSAP, approximately 140,000 skipjack were tagged during the period October 1977 and August 1980 (Kleiber et al., 1983). Fish were released throughout the SPC statistical area from Palau to French Polynesia and more than 6,000 tag returns, mostly the result of recapture by pole-and-line vessels, were received. Skipjack was the target species of the SSAP; only 9,000 yellowfin and less than 100 bigeye were tagged.

The RTTP began in July 1989, with tagging continuing until December 1992. A total of 132,779 releases[1] were distributed from the Philippines and eastern Indonesia to about 180°, across a latitudinal range of 10°N–20°S (Figure 6). Unlike the SSAP, the RTTP attempted to release large numbers of yellowfin and bigeye; approximately 34,000 yellowfin and 7,000 bigeye were released along with 92,000 skipjack. As of 30 June 1994, 14,635 returns had been received, with return rates for skipjack and yellowfin of about 11% and for bigeye of about 7%. Small numbers of returns continue to be received.

Both projects made visits to Kiribati, and to the Gilbert Islands in particular. In the Gilbert Islands area defined for the purpose of this study (5°N–5°S, 168°E–180°), 4,569 skipjack were released by the SSAP, mostly in July 1978. Most releases were made in the vicinity of Butaritari. Recaptures were recorded from two survey vessels (JICA and FAO/UNDP) fishing near the release site (346), the Japanese pole-and-line fleet fishing in the area (27), the SSAP tagging vessel (10) and artisanal fishermen (2). Most of these recaptures occurred in the Gilbert Islands area. Locally, movements were mostly to the east, west and south of the main release site (Kleiber and Kearney 1983).

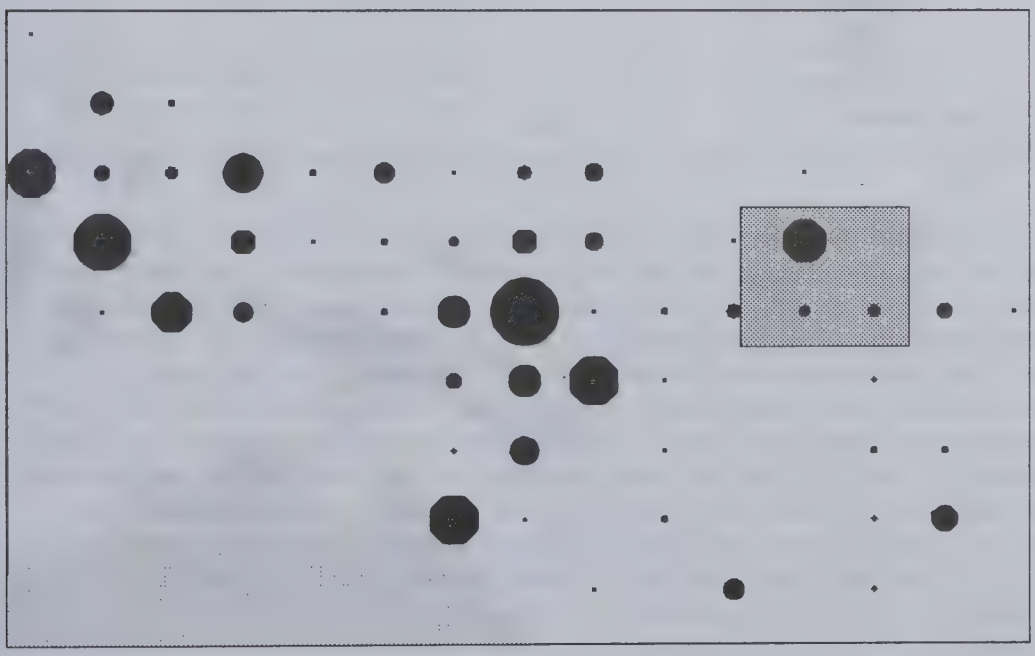

Figure 6. Distribution of RTTP releases (all species). The maximum circle size represents 23,000 releases. The rectangle indicates the Gilbert Islands area.

The RTTP visited the Gilbert Islands area in October 1990, August–September 1991 and March–April 1992, releasing a total of 14,427 tagged tuna (10,070 skipjack, 2,787 yellowfin and 580 bigeye). Most releases were made in the vicinity of Maiana and Abemama (Figure 7). Of these releases, 779 skipjack, 212 yellowfin and 63 bigeye have

[1] These figures do not include an additional 13,695 tuna tagged in a dedicated research project in the Philippines in August–October 1992, or the subsequent 3,563 recoveries.

been recovered and the tags returned. In contrast to the SSAP recaptures, many of the RTTP recaptures were made outside the Gilbert Islands area (Figure 8). Of the recaptures within the Gilbert Islands area, most were made by USA purse seine vessels in the area surrounding the Gilbert Islands chain. Smaller numbers were recaptured by TML pole-and-line vessels and artisanal skiffs close to the release locations (see Table 13 for details of recapture numbers by fleet).

Table 13. Release and return numbers for tuna released in the Gilbert Islands area during the RTTP. Local recaptures refers to recaptures within the 200 nm zone surrounding the Gilbert Islands. Regional recaptures refers to recaptures outside this area.

Release/recapture category	Skipjack	Yellowfin	Bigeye	Total
Releases	10,070	2,787	580	13,437
Local recaptures				
Tagging vessel	4			4
TML PL	68	5		73
Artisanal	2	3		5
Japan PL	1			1
Japan PS	1			1
USA PS	152	27	17	196
Sub-total	228	35	17	280
Regional recaptures	551	178	47	776
Total	779	213	64	1,056

In this section, we analyse the RTTP skipjack and yellowfin data for the Gilbert Islands area first using a simple aggregate tag-attrition model. The objective of this analysis is to derive estimates of the natural mortality/emigration rate and fishing mortality rates by the DWFN purse seine, TML pole-and-line and artisanal fleets operating in the Gilbert Islands area. These estimates can then be used to develop estimates of interaction among the fleets, assuming that the skipjack and yellowfin in the Gilbert Islands area are simultaneously available to all fleets. We then carry out a regional analysis of the skipjack data using a model with fine-scale spatial resolution in order to estimate the average effect of the total western Pacific purse seine fisheries on the TML pole-and-line fleet. This model explicitly recognises the different spatial distributions of effort of the different fleets, as well as the skipjack movement pattern, natural mortality rate and catchability as estimated from the RTTP tagging data.

3.2 Interaction Analysis Using a Simple Tag-Attrition Model

Tag-attrition models have been used extensively to analyse time series of tagging data, usually aggregated over some defined area, for the purpose of estimating mortality rates, standing stocks, turnover rates and throughputs. Kleiber et al. (1983) described the basic models and applied them to various SSAP data sets. Kleiber and Kearney (1983) described an application to SSAP data for Kiribati. In this section, we use two versions of the tag-attrition model to analyse RTTP tagging data for the Gilbert Islands area, and use the results of one to develop estimates of interaction.

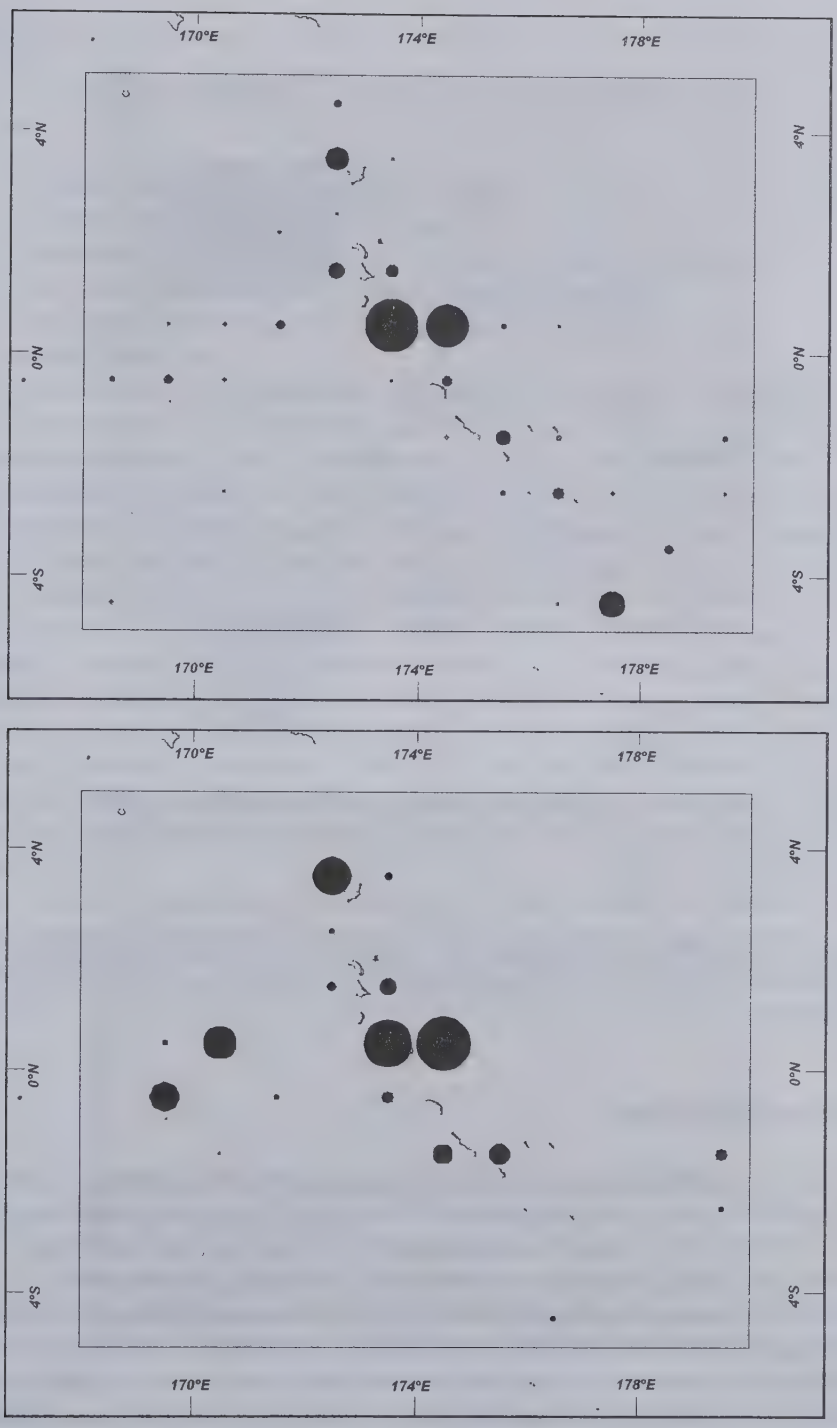

Figure 7. Distribution of skipjack (top) and yellowfin (bottom) releases in the vicinity of the Gilbert Islands. The maximum circle size represents 3,700 skipjack releases and 750 yellowfin releases.

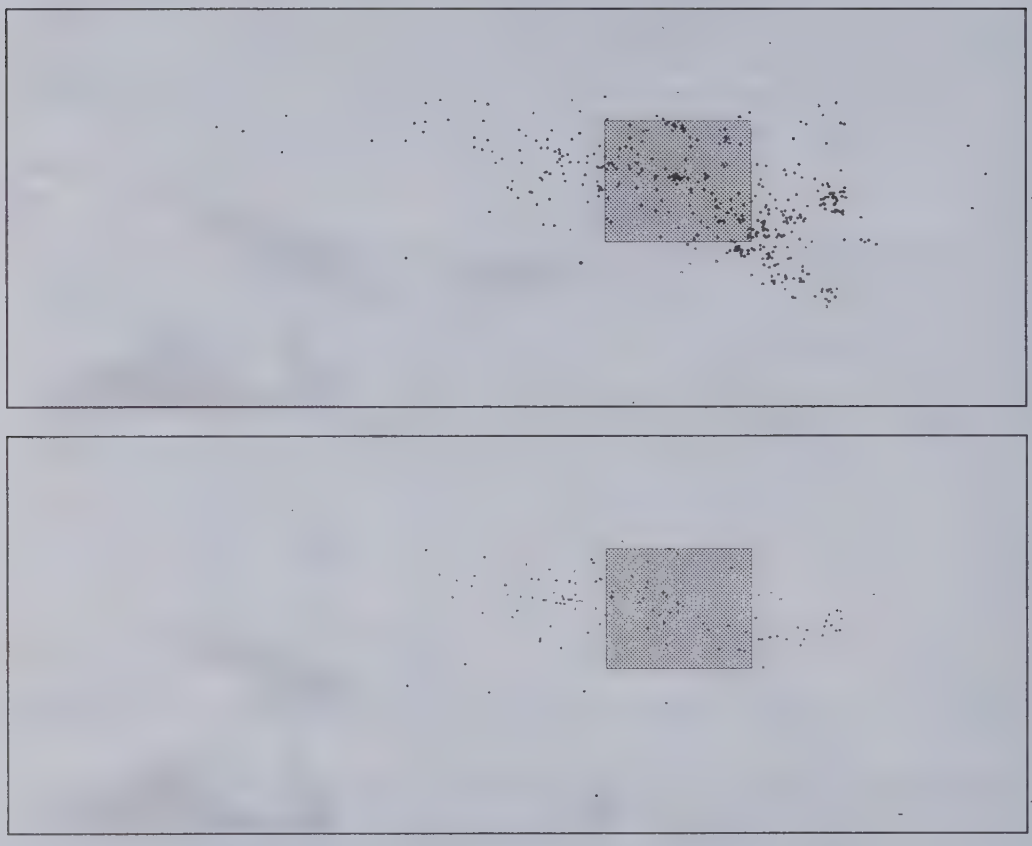

Figure 8. Distribution of skipjack (top) and yellowfin (bottom) recaptures from releases in the vicinity of the Gilbert Islands. The rectangle indicates the Gilbert Islands area.

3.2.1 Tag-attrition models

A tag-attrition model describes the rate of decrease in tag-return rate over time, and attempts to estimate the various components of this rate of decrease, or attrition, that are of interest. Attrition occurs because natural mortality, fishing mortality and emigration reduce the size of the tagged population over time. For ease of mathematical representation, we usually assume that these processes occur continuously over time, although the rates themselves may be allowed to vary under some circumstances. If the disaggregation of attrition into its components is to be unbiased, we must also account for other losses of tags, such as non-reporting and tag shedding. The two equations that we generally use to predict the number of tag returns $\hat{r}_{ij}$ during time period i by fishing fleet j are

$$\hat{r}_{ij} = \alpha\beta N_i \frac{F_{ij}}{\sum_j F_{ij} + M}\left[1 - \exp\left(-\sum_j F_{ij} - M\right)\right] \qquad (3.1)$$

and

$$N_{i+1} = N_i \exp\left(-\sum_j F_{ij} - M\right) + R_{i+1} \qquad (3.2)$$

where a is the survival rate from immediate tag loss;
b is the reporting rate of recaptured tags;
N_i is the number of tagged tuna alive at the beginning of period i;
F_{ij} is the fishing mortality rate in time period i by fleet j;
M is the rate of natural mortality plus emigration from the area under consideration; and
R_i is the number of tag releases in time period i (assumed, for simplicity, to have occurred at the start of the time period).

Note that the tagged population N_i in month i can consist of tagged tuna that were released in a variety of different months. This type of structure has been termed the pooled or aggregate cohort structure (Kleiber and Hampton, 1994; Sibert et al., 1996). This essentially involves the assumption that tuna released in different "cohorts" (here, a cohort is simply defined by a release month) have similar mortality and vulnerability characteristics. Another key assumption of the model is that the tagged population is immediately and equally available to each fishing fleet upon release. As we shall see, this assumption is difficult to satisfy in practice where the area is large and the effort distributions of the fleets are different. We also had to assume a value for the product ab, as it is generally difficult to estimate independently from the tag return data. Based on various auxiliary information (tag shedding, tag seeding, etc.), a value of 0.6 was used in the estimations.

The parameters to be estimated are M and F_{ij}. In practice, we usually cannot independently estimate i x j fishing mortality rates; F_{ij} is usually assumed constant across time periods or is re-parameterised in terms of either catch C_{ij} or effort f_{ij}.

$$F_{ij} \approx \frac{C_{ij}}{\overline{P}} \quad \text{or} \quad F_{ij} = q_j f_{ij} \qquad (3.3)$$

In the latter case, the estimated parameters are either the standing stock $\overline{P}$ or catchability coefficients for each fleet q_j.

We fitted models to the tagging data using both the catch and effort re-parameterisations of fishing mortality. Only recaptures from the Gilbert Islands area were included in the analysis. Actual catch and effort data for the purse seine fleet and TML pole-and-line fleet were used in the analysis. Reliable estimates of catch and effort for the artisanal fleet were not available, so constant, "dummy" values were used, which essentially constrained fishing mortality for this fleet to be constant. In the case of catch data, estimates based on Table 1 and a total artisanal catch of 11,500 mt (Mees et al., 1988) were used. The complete data sets used in the estimations are given in Table 14.

A Poisson likelihood function was used to fit the model. The likelihood of the tag recapture data **r** given the model, the release numbers and the catch or effort data is therefore

$$\ell(\mathbf{r}|\hat{\mathbf{r}}) = \prod_i \frac{\hat{r}_i^{r_i}}{\exp(\hat{r}_i) r_i!} \qquad (3.4)$$

Should be likelihood of ob given model

$\ell(\hat{r}|r)$

Table 14. Data used in fitting the models. PS, PL and Art refer to the purse seine, TML pole-and-line and artisanal fleets, respectively.

Month	Skipjack				Yellowfin				Effort (days)			Skipjack catch (t)			Yellowfin catch (t)		
	Releases	Recaptures			Releases	Recaptures			PS	PL	Art.	PS	PL	Art.	PS	PL	Art.
		PS	PL	Art.		PS	PL	Art.									
90-10	644	0	0	0	156	0	0	1	81	2	10	195.9	0.0	23	4,064.6	0.0	364
90-11	0	0	0	1	0	0	0	0	266	0	10	1,372.3	0.0	23	2,072.7	0.0	364
90-12	0	0	0	0	0	0	0	0	259	0	10	4,784.6	0.0	23	500.4	0.0	364
91-01	0	0	0	0	0	0	0	0	28	0	10	10.0	0.0	23	0.0	0.0	364
91-02	0	0	0	0	0	0	0	0	10	0	10	0.0	0.0	23	0.0	0.0	364
91-03	0	0	0	0	0	0	0	0	7	0	10	0.0	0.0	23	0.0	0.0	364
91-04	0	0	0	0	0	0	0	0	5	0	10	0.0	0.0	23	0.0	0.0	364
91-05	0	0	0	0	0	0	0	0	55	5	10	1,942.8	0.5	23	4.5	0.5	364
91-06	0	0	0	0	0	0	0	0	324	0	10	9,955.9	0.0	23	165.5	0.0	364
91-07	0	1	0	0	0	0	0	0	266	20	10	14,095.0	9.9	23	76.9	15.8	364
91-08	5,479	0	5	0	1,257	0	0	0	49	22	10	2,652.7	16.6	23	75.3	25.3	364
91-09	2,952	6	28	0	798	0	2	0	51	26	10	666.2	8.4	23	12.0	13.2	364
91-10	0	6	25	1	0	1	0	1	156	30	10	3,294.4	24.4	23	743.6	29.0	364
91-11	0	23	10	0	0	5	3	1	87	32	10	914.4	6.3	23	167.7	15.2	364
91-12	0	0	0	0	0	0	0	0	34	43	10	238.6	3.2	23	37.2	6.8	364
92-01	0	1	0	0	0	1	0	0	88	42	10	464.4	10.3	23	725.9	8.6	364
92-02	0	1	0	0	0	0	0	0	135	55	10	973.1	18.2	23	2,336.9	20.7	364
92-03	178	6	0	0	195	2	0	0	419	54	10	7,303.7	31.4	23	3,427.1	60.2	364
92-04	813	0	0	0	371	1	0	0	229	31	10	5,817.8	6.9	23	3,573.3	17.2	364
92-05	0	4	0	0	0	0	0	0	93	31	10	2,055.2	6.2	23	1,032.1	6.5	364
92-06	0	5	0	0	0	2	0	0	101	25	10	3,453.3	11.6	23	289.0	10.9	364
92-07	11	26	0	0	10	1	0	0	342	26	10	13,852.3	4.3	23	306.5	9.7	364
92-08	0	2	0	0	0	0	0	0	89	32	10	829.3	15.7	23	264.7	25.5	364
92-09	0	22	0	0	0	3	0	0	194	37	10	6,012.4	36.3	23	566.3	31.4	364
92-10	0	9	0	0	0	0	0	0	192	49	10	3,827.7	24.7	23	721.0	18.2	364
92-11	0	4	0	0	0	2	0	0	312	34	10	6,689.5	26.2	23	1,119.2	12.2	364
92-12	0	14	0	0	0	0	0	0	346	13	10	8,066.5	4.0	23	814.3	12.6	364
93-01	0	11	0	0	0	3	0	0	459	10	10	9,986.2	0.7	23	919.9	1.9	364
93-02	0	4	0	0	0	1	0	0	325	22	10	4,140.4	11.2	23	2,728.2	15.6	364
93-03	0	3	0	0	0	1	0	0	492	47	10	12,407.2	19.8	23	4,684.7	11.4	364
93-04	0	2	0	0	0	2	0	0	205	42	10	1,689.2	23.2	23	1,492.2	10.4	364
93-05	0	0	0	0	0	0	0	0	390	22	10	6,767.7	15.0	23	1,457.2	3.2	364
93-06	0	0	0	0	0	1	0	0	392	25	10	12,094.2	13.8	23	3,642.4	11.3	364
93-07	0	0	0	0	0	1	0	0	491	33	10	13,070.0	8.7	23	7,088.1	22.5	364
93-08	0	0	0	0	0	0	0	0	390	14	10	5,638.6	0.0	23	3,524.2	2.8	364
93-09	0	1	0	0	0	0	0	0	746	23	10	12,602.8	1.1	23	8,795.3	10.0	364
93-10	0	1	0	0	0	0	0	0	446	15	10	7,115.2	0.0	23	1,015.4	6.0	364
93-11	0	0	0	0	0	0	0	0	253	1	10	2,502.3	0.0	23	531.8	0.0	364
93-12	0	0	0	0	0	0	0	0	563	12	10	10,355.2	5.2	23	510.8	0.0	364

3.2.2 Results and discussion

The estimated natural mortality rates are high relative to estimates for the region as a whole (SPC, 1994) and obviously contain a large component of emigration (Table 15). This is further suggested by the fact that much larger recapture numbers were recorded outside the Gilbert Islands area (see "Regional returns" in Table 13). Estimated total fishing mortality rates are low compared with regional estimates (SPC, 1994) and reflect the low recovery rate of tags within the Gilbert Islands area (2.3% for skipjack, 1.3% for yellowfin). Most of the fishing mortality that did occur was attributed to the purse seine fleet, again reflecting the distribution of tag returns among the fleets.

Table 15. Parameter estimates obtained from the tag-attrition model fits to RTTP Kiribati tagging data. All rates are per month; $\overline{P}$ and T ($T = Z\overline{P}$) are in mt.

	Skipjack	Yellowfin
Effort parameterisation		
M	0.179	0.157
q purse seine	3.30E-05	1.59E-05
q pole-and-line	6.71E-05	1.54E-05
q artisanal	6.81E-06	2.91E-05
F purse seine average	0.00793	0.00381
F pole-and-line average	0.00151	0.000346
F artisanal average	6.18E-05	0.000291
Z average	0.189	0.161
Catch parameterisation		
M	0.203	0.155
$\overline{P}$	367,047	424,642
F purse seine average	0.0138	0.0036
F pole-and-line average	2.54E-05	2.63E-05
F artisanal average	6.27E-05	0.0009
Z average	0.217	0.159
T	79,767	67,723

The fits of the models to the observed tag returns are poor (Figure 9). Returns in periods soon after tags were released are generally under-estimated by the model for the TML pole-and-line fleet. This is likely to be because most tag releases were made in the vicinity of Maiana and Abemama, which is an area favoured by the TML fleet. Most of the returns by this fleet therefore resulted from fishing in the vicinity of the tag releases before the tagged fish had dispersed. Conversely, the model tends to over-estimate purse seine returns during these initial periods because movement away from the release sites to surrounding areas where purse seiners fish (outside the 12 nm territorial limit) had not yet occurred. Very few tagged skipjack or yellowfin were recaptured by the artisanal fleet. The model, which can predict fractional returns, will not be able to accurately predict very small integer numbers of observed returns, hence the apparent lack of fit to these returns in Figure 9.

Clearly, this type of spatially aggregated model, which takes no account of tuna movement or the spatial distributions of releases and fishing effort, does not provide a very

adequate representation tagged tuna dynamics in the Gilbert Islands area. Nevertheless, it is possible that some general features of skipjack and yellowfin exploitation (such as relative average fishing mortality rates by the different gear types and stock turnover rates in the area) have been captured by the analysis, at least in approximate form. We will therefore proceed with an analysis of interaction using the results obtained from the model with the catch re-parameterisation of fishing mortality. This form of the model is convenient for the interaction analysis because the standing stock estimate allows an estimate of average throughput, T, to be determined by

$$T = Z\bar{P} \tag{3.5}$$

where $Z=F_{av}+M$. We wish to estimate the impact on pole-and-line catch C_p and artisanal catch C_a of different levels of purse seine catch C_s. Assuming that average fishing effort by the pole-and-line and artisanal fleets remains constant (and hence their fleet-specific average fishing mortality rates remain constant) and the level of throughput remains constant for various levels of catch and local standing stock, the relationship between the three catch levels is defined by the following series of equations:

$$\bar{P}_{\text{new}} = \frac{T - C_s}{M + F_p + F_a} \tag{3.6}$$

$$C_p = F_p \bar{P}_{\text{new}} \quad \text{and} \quad C_a = F_a \bar{P}_{\text{new}} \tag{3.7}$$

where $\bar{P}_{\text{new}}$ is the new equilibrium standing stock under the new catch regime. The percentage change in pole-and-line and artisanal catches in response to various percentage changes in purse seine catch are shown in Figure 10 (only one response curve for each species is shown as the changes in pole-and-line and artisanal catches in percentage terms are identical). The levels of interaction appear slight – about a 7% reduction in equilibrium pole-and-line and artisanal skipjack catches results from the October 1990–December 1993 average purse seine catch of 5,000 mt per month (compared to the equilibrium catches that would be attained with zero purse seine catch). The corresponding results for yellowfin are a 3% reduction in equilibrium pole-and-line and artisanal catches for the average purse seine catch of 1,500 mt per month.

As noted above, the confidence that we can place in these results is limited by the poor quality of the fits of the tag-attrition model to the tag recapture data. These deficiencies seem to result from lack of spatial resolution in the model. Also, the lack of spatial resolution and the small reference area (Gilbert Islands) for the analysis means that interaction effects of the purse seine fishery on a regional scale cannot be assessed. In the next section, we attempt to address these difficulties by using a high-resolution spatial model to assess the effect of the regional purse seine fishery on the skipjack catch of the TML pole-and-line fleet.

3.3 Interaction Analysis Using a High-Resolution Spatial Model

The effect of the large-scale purse seine fishery on the Kiribati pole-and-line fishery can be analysed using a population dynamics model having relatively detailed spatial resolution. Such a model has been described by Sibert and Fournier (1993) and Sibert et al. (1996).

The advantage of using this type of model over the spatially-aggregated tag-attrition model is that more detailed information regarding the spatial distribution of effort and regional variation in movement pattern can be incorporated into the analysis. We used such a model to firstly estimate the skipjack population and fishery parameters from RTTP tagging data, and secondly to apply these estimated parameters in a population biomass simulation in which purse seine effort was manipulated and the resulting effects on Kiribati pole-and-line catch observed. Potentially, the same analysis could be carried out for yellowfin and could include the Kiribati artisanal fishery (given data of the required resolution), but this has not yet been attempted.

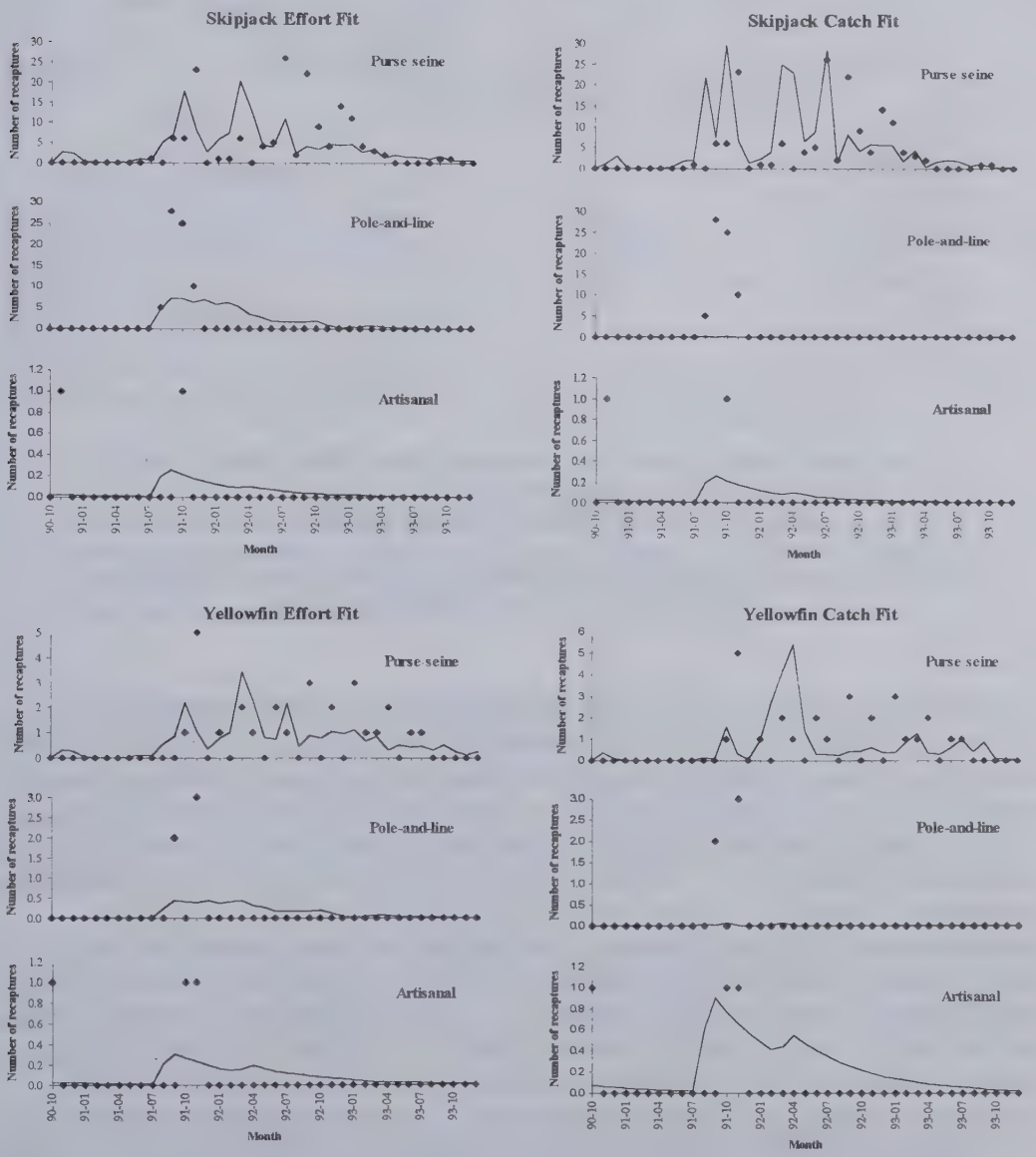

Figure 9. Fits of the models (solid lines) to the observed tag recapture data.

3.3.1 Estimation model – methods and data

We applied the model described in Sibert et al. (1996) to RTTP skipjack data to estimate parameters that would provide the basis for the interaction analysis. The spatial resolution of the model was a 1° by 1° grid on the area 10°N–25°S, 130°E–170°W, with land masses excluded as shown in Figure 11. A monthly time step over the period July 1989–December 1993 was used, and a total of 230 tagged skipjack cohorts (a cohort being defined as a group of tagged skipjack released in a particular spatial cell in a particular month) defined. The spatial distribution of these releases is also shown in Figure 11.

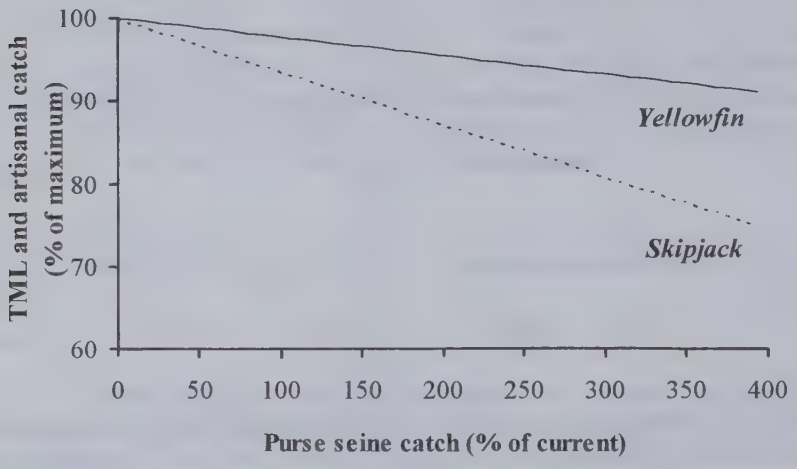

Figure 10. Response of the TML pole-and-line and artisanal catch rates to changes in purse seine catch in the Gilbert Islands area.

These fleets accounted for 92% of all skipjack tag returns within the study area. However, many returns for some fleets could not be incorporated into the estimation model because the precision of the recapture data was less than the 1° square–month resolution required. This was a major problem with the Korean and Taiwanese purse seine fleets; recapture locations were rarely available because the tags were generally recovered in canneries after transshipment. We dealt with this problem, and the problem of incomplete tag reporting generally, by introducing a series of specified reporting rates into the estimation model (in a similar fashion as was done with the simple tag-attrition model). A global reporting rate of 0.923 was used to account for the proportion of total tag returns attributable to the fleets included in the analysis. A series of fleet-specific reporting rates was also applied. These reporting rates accounted for the variable performance of the fleets in returning tags at all, and returning them with sufficiently accurate recapture information to allow their inclusion in the analysis. The proportions of tags reported for each fleet were estimated from tag-seeding experiments and other information (SPC, 1994). The proportions of returned tags that had usable recapture information were computed from the tag returns for each fleet. These proportions and their product, which represents the overall fleet-specific vector of reporting rate, are shown in Table 16.

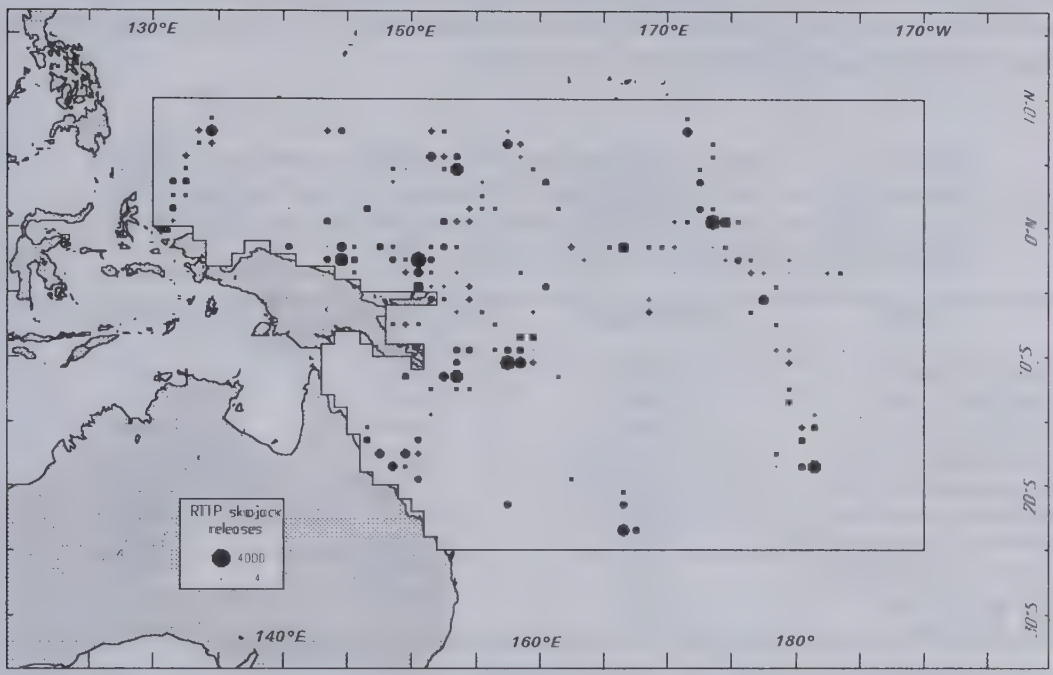

Figure 11. Spatial distribution of tagged skipjack releases analysed using the high-resolution spatial model. The solid line indicates the spatial boundary of the model. Four pole-and-line (Japan, Fiji, Solomon Islands and Kiribati) and six purse seine fleets (Japan, USA, Korea, Taiwan, Philippines and Solomon Islands) were individually treated in the model. Their effort distributions during the study period are shown in Figure 12.

Skipjack movement was parameterised according to regions and seasons, as described in Sibert et al. (1996). Movement was represented by directed (advective) and random (diffusive) components, with the two advection (north↔south and east↔west) and one diffusion parameters assumed to be constant in time and space within regions and seasons. Catchability coefficients for each fleet and the instantaneous rate of natural mortality were assumed to be constant across regions and seasons.

The definition of regions and seasons was somewhat arbitrary, although different structures can be compared using the log-likelihood values of the maximum likelihood solutions. We chose a ten-region and two-season (April–September, October–March) stratification, as shown in Figure 13.

With this model structure, 71 parameters were required to be estimated – one natural mortality rate, ten catchability coefficients (one for each fleet) and sixty movement parameters (two advection and one diffusion parameter for each region-season stratum). As for the aggregate tag-attrition model, we used the "pooled cohort" version of the model, whereby tagged skipjack behaviour is assumed to be independent of their release cohort

(see Sibert et al., 1996, for details). This effectively means that the release of tagged skipjack occurs as a series of events analogous to "recruitment", and that members of a particular cohort subsequently become indistinguishable from other tagged skipjack that occur in the same grid cell during the same month.

Table 16. Tag reporting rates and proportions of usable tag return data, by fleet. For each fleet, the overall "reporting rate" is the product of the fleet-specific tag reporting rate, the proportion of usable data, and the proportion of all tag returns attributable to the fleets included in the analysis (0.923).

Fleet	Reporting rate	Proportion of usable data	Overall "reporting rate"
Fiji pole-and-line	0.900	0.994	0.826
Japan pole-and-line	0.417	0.977	0.376
Japan purse seine	0.420	0.928	0.360
Kiribati pole-and-line	0.700	1.000	0.646
Korean purse seine	0.263	0.105	0.025
Philippines purse seine	0.799	0.904	0.667
Solomon Is. pole-and-line	0.899	0.795	0.660
Solomon Is. purse seine	0.892	0.866	0.713
Taiwan purse seine	0.394	0.043	0.016
USA purse seine	0.728	0.757	0.509

For any set of model parameters, a complete set of tag returns by fleet, grid cell and month can be simulated, using the observed distributions of tag releases (by grid cell and month) and fishing effort (by fleet, grid cell and month) to drive the simulation. We used non-linear optimisation methodology (see Sibert et al., 1996, for details) to find the set of model parameters that resulted in the best fit of observed and simulated tag returns according to a Poisson likelihood function. Details of the likelihood function and equations used for simulating the tag returns are given in Sibert et al. (1996).

If the estimated parameters are to be interpreted as representative of the population in general (i.e., not just the tagged population), we need to assume that the probability of capture of tagged skipjack within a grid cell-month stratum is the same for untagged fish. This might not be the case, particularly soon after release, if the tagged and untagged fish are not randomly mixed within the grid cell and the distribution of fishing effort is also non-random, such that the tagged fish are either more or less likely to be captured than untagged fish. We found some evidence of this in the RTTP skipjack data; for several tagged cohorts released in the vicinity of fish aggregating devices (FADs), the number of recaptures in the first month after release in the grid cell of release was either much greater or much fewer than expected by the model. We interpret this as resulting from short-term retention of the tagged skipjack near the release site by the FADs (thus inhibiting mixing). Large numbers of returns would occur in the first month if effort occurred at the release site (FAD), whereas few returns would occur if no fishing occurred at the release site. To avoid biased parameter estimates that might result because of lack of mixing in the first month, we excluded seven release cohorts from the analysis (February 1991 releases in the Solomon Sea) that showed extreme symptoms of non-mixing.

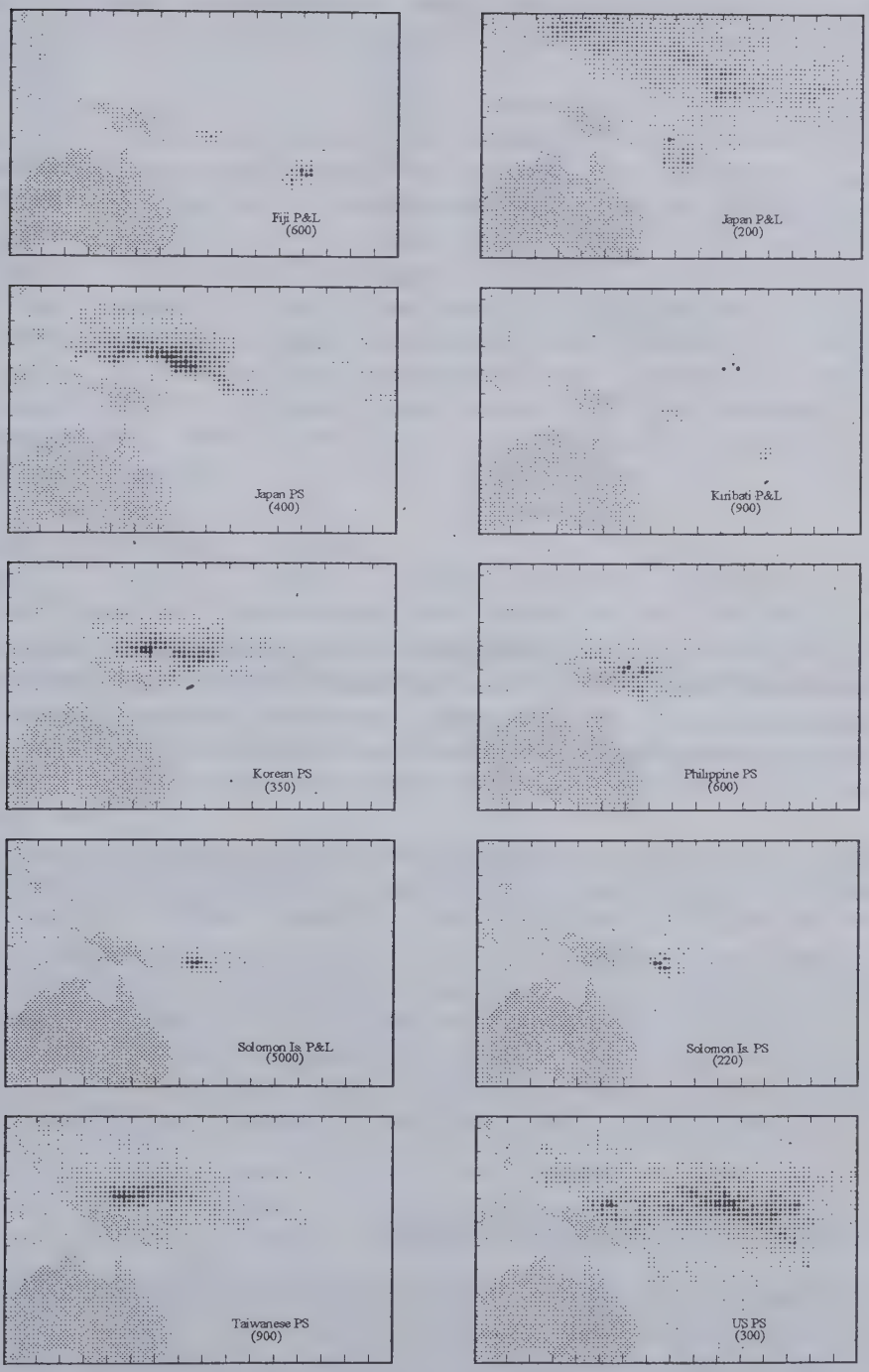

Figure 12. Effort distributions for the fleets included in the high-resolution spatial analysis. The time period covered is July 1989–December 1993. The effort (days fished) represented by the maximum circle size is given in parentheses for each fleet. The solid line indicates the model area boundary.

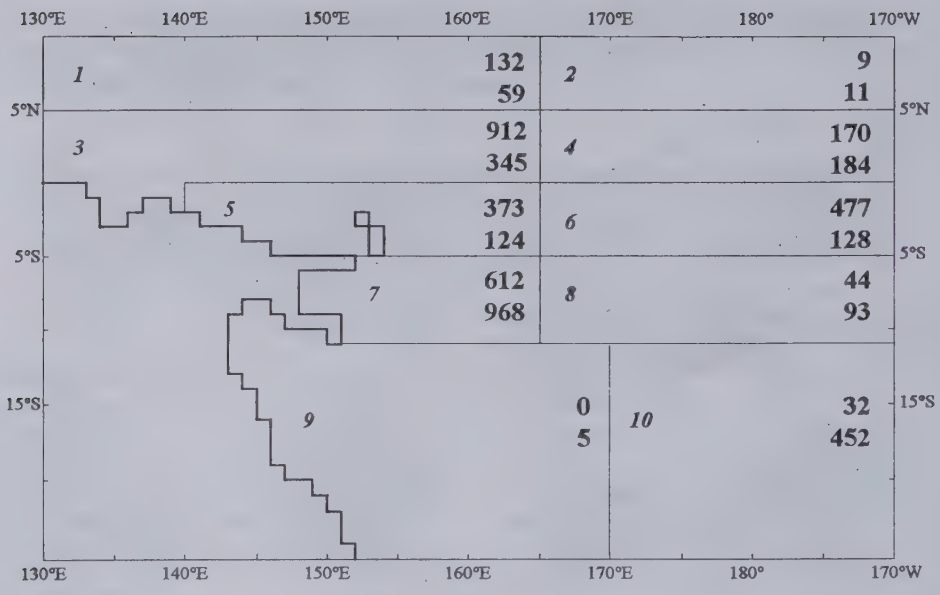

Figure 13. The definition of the ten regions in the high-resolution model. The numbers near the right boundary of each region are the numbers of usable skipjack tag returns for season 1 (April – September, upper number) and season 2 (October – March, lower number).

Boundary conditions for the model need to be specified. Boundaries comprised of cells that consist of land (e.g., the east coast of Australia) are obviously non-permeable and were assumed in the model to be closed and reflective. Boundaries that are comprised of open cells (i.e., water) may be considered permeable, in which case fish are assumed to be able to migrate out of the study area, or closed and reflective as for land-mass boundaries. The former assumption would be reasonable if the study area was a substantially smaller sub-area of the total known stock area, while the latter assumption would be appropriate if the boundaries were thought to represent approximate limits to the distribution of at least the majority of the stock. For the results reported here, we assumed that all boundaries were closed.

3.3.2 Estimation model – results and discussion

In preliminary fits of the model to the RTTP tagging data, we attempted to estimate all 71 parameters using a sequential parameter relaxation procedure. In most of the fits so far carried out, the estimated value of M converged to biologically unreasonable values very close to zero. The reasons for this are not yet clear and are the subject of further investigation. For the purpose of deriving parameters that could be used in the interaction analysis, two fits with fixed M were carried out. In fit 1, M was fixed at 0.1 mo^{-1}, a value consistent with estimates from a spatially aggregated analysis of RTTP tagging data (SPC, 1994). In fit 2, M was fixed at 0.05 mo^{-1} to see if the results of the interaction analysis were sensitive to this assumption. The parameter estimates for the two fits are given in

Tables 17 and 18, respectively. The estimated movement patterns for the two fits are similar in most respects although there are some differences in the advection parameters in particular for areas 9 and 10 (Figures 14 and 15). The catchability coefficients are slightly smaller in fit 2.

It is difficult to display the fits in relation to the observed data because of the multi-dimensional nature of the model. Some sense of goodness of fit can however be gained from plots of spatially aggregated observed and predicted tag returns over time (Figure 16). It is clear that there are some deficiencies in the fits, particularly with the under-estimation of recoveries in months 24 and 27 and the over-estimation of recoveries by the model during the last 12 months of the time series. Some of the larger discrepancies might be due to non-compliance with the assumption of complete and immediate mixing within one-degree squares. The lower than expected numbers of returns at the end of the time series might be due to declines in tag reporting rates, although there is no evidence of this is the tag-seeding data (SPC, 1994). Further investigation of these matters is required and will be undertaken in due course.

3.3.3 Biomass simulation – methods

We used a population biomass simulation to investigate the long-term average impact of the large-scale purse seine fishery on the Kiribati pole-and-line fishery. The simulation model has the same structure as the tag estimation model with the following adaptations:

- The density of population biomass and skipjack catches by the various fleets by 1° square and month are modelled instead of the density of tagged skipjack and tag returns; and
- Skipjack recruitment (in biomass) by 1° square and month rather than the release numbers of tagged skipjack define the initial conditions of the model.

The natural mortality, catchability and movement parameters estimated (or assumed) for tagged skipjack, along with monthly effort by 1° square for each fleet averaged over the period 1989-93 were used to predict the catches by each fleet. Recruitment was assumed to be uniform in space and time across the model area for the duration of the simulation. Arbitrary biomass units were used to define recruitment, with the resulting population biomass and catches taking the same units. Simulations were initiated by allowing the model to run for a ten-year period with only the four pole-and-line fleets active. This "spinning-up" period is necessary to allow the population to build up and reach an equilibrium; at the end of this period, we have a stable population being exploited by pole-and-line fleets at their 1989-93 average levels of effort with no purse seine fishing. Interaction is measured by the decline in pole-and-line catch at various levels of purse seine catch and effort. Catches by the Kiribati and other pole-and-line fleets at the end of the initial ten-year period thus provide a reference point against which later catches at various levels of purse seine effort can be compared.

The six purse seine fleets begin fishing in year 11 of the simulation. Their effort increases in ten increments, with each increment representing 20% of their 1989-93 average effort. The simulation is allowed to run for three years (using the fit 1 parameters)

or five years (using the fit 2 parameters) at each purse seine effort level to allow the population and catches to re-equilibrate. (A longer equilibration period for fit 2 parameters was required because of the lower M.) At the end of the simulation (40 or 60 years), purse seine effort is twice its 1989-93 average level. The difference in pole-and-line catches between those in year 10 (no purse seine effort) and those at the end of each incremental period is a measure of the impact of the respective purse seine catches.

3.3.4 Biomass simulation – results and discussion

The results of the simulations are summarised in Figure 17. The simulations indicate that average Kiribati pole-and-line catch is reduced by about 10% (fit 1) to 12% (fit 2) from its predicted level in the absence of purse seining when the 1989-93 average purse seine effort is applied. Pole-and-line catches decline at similar rates for further increases in purse seine effort.

The impact of purse seining on the other pole-and-line fleets appears to vary according to the fishing location of the fleet. Fiji pole-and-line catches, which are largely taken in the vicinity of Fiji, well to the south of the main purse seine fishing area, are the least affected by purse seine catches. The greater impact on Fiji pole-and-line catches in fit 2 is probably because of the differences between fits in estimated advection in area 10 in season 1 (northwesterly in fit 1, southeasterly in fit 2). Similarly, the impact of purse seine catches on the Solomon Islands pole-and-line fleet are estimated to be slight. Large-scale purse seining occurs mainly to the north of the Solomon Islands, with only a few domestic vessels fishing in close proximity to the pole-and-line fleet. Also, estimated diffusion and advection are small in area 7, inferring some degree of localisation of the skipjack population in this area. The Japanese and Kiribati pole-and-line fleets, which have effort distributions overlapping with the large-scale purse seine fishery, predictably show the highest levels of interaction.

4. GENERAL DISCUSSION

Several different approaches were taken in this study to investigate the impact of purse seine fishing on the domestic pole-and-line and artisanal fisheries operating in the vicinity of the Gilbert Islands of Kiribati. We first examined survey data for the artisanal troll fishery and attempted to correlate surveyed yellowfin catch rates with yellowfin catches by large-scale purse seiners fishing at varying distances from the survey locations and at varying time periods prior to surveys. For large areas around the surveyed island, e.g., 300 or 600 nm, the correlations were generally positive, suggesting that variability in yellowfin abundance had at least the same directional impact on purse seine catch and artisanal catch rate – when purse seine catches are high, artisanal catch rates also tend to be high. For areas of 50 or 60 nm around a surveyed island, negative correlations between purse seine catch and artisanal catch rate were common, although these were not generally significant when zero purse seine catches were included in the analysis. There is, therefore, some empirical evidence that purse seine catches of yellowfin affect artisanal troll catch rates on small spatial scales through direct competition.

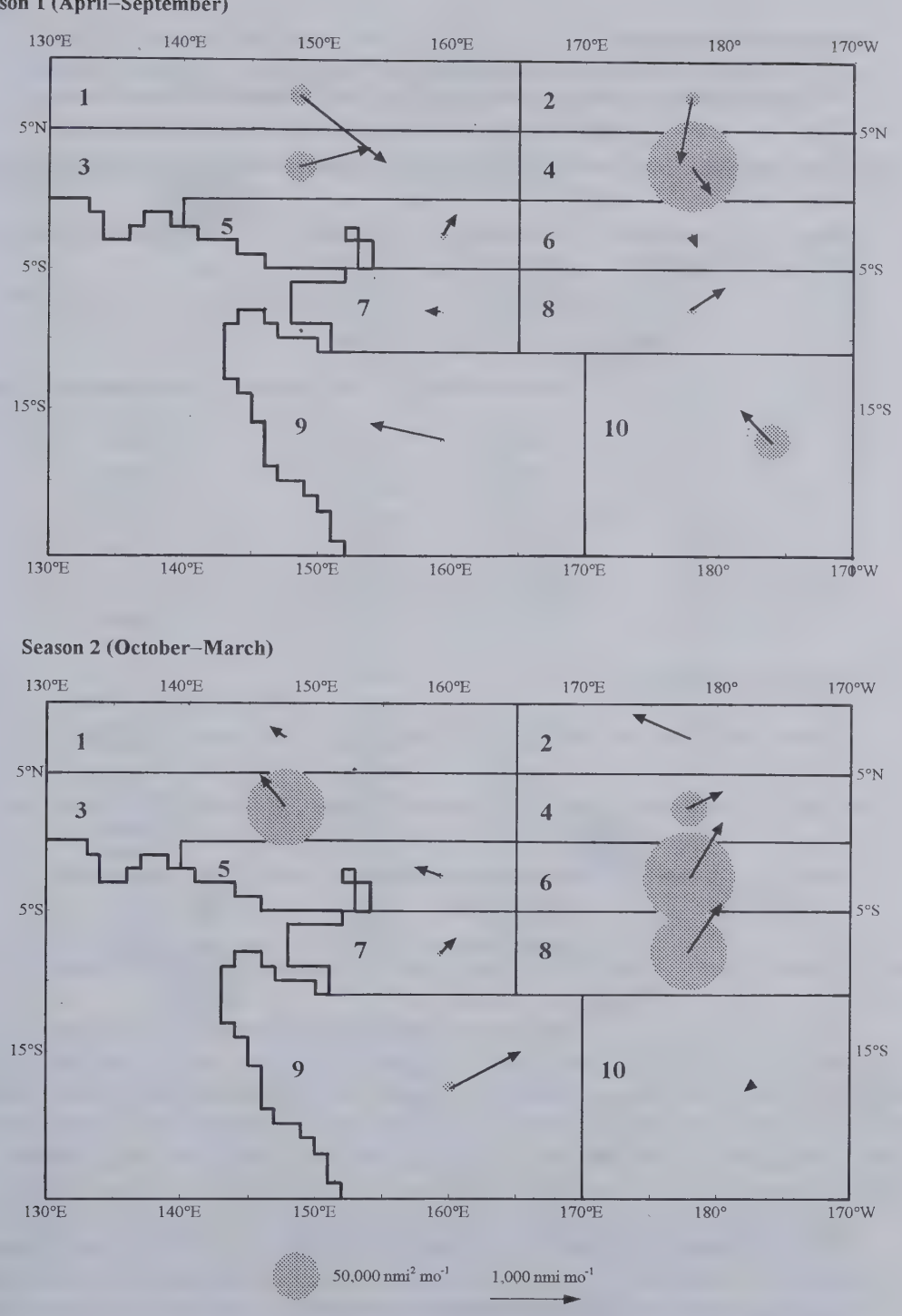

Figure 14. Graphical representation of estimated movement parameters for fit 1 (M=0.1 mo^{-1}). The arrows represent advection and the circles represent diffusion.

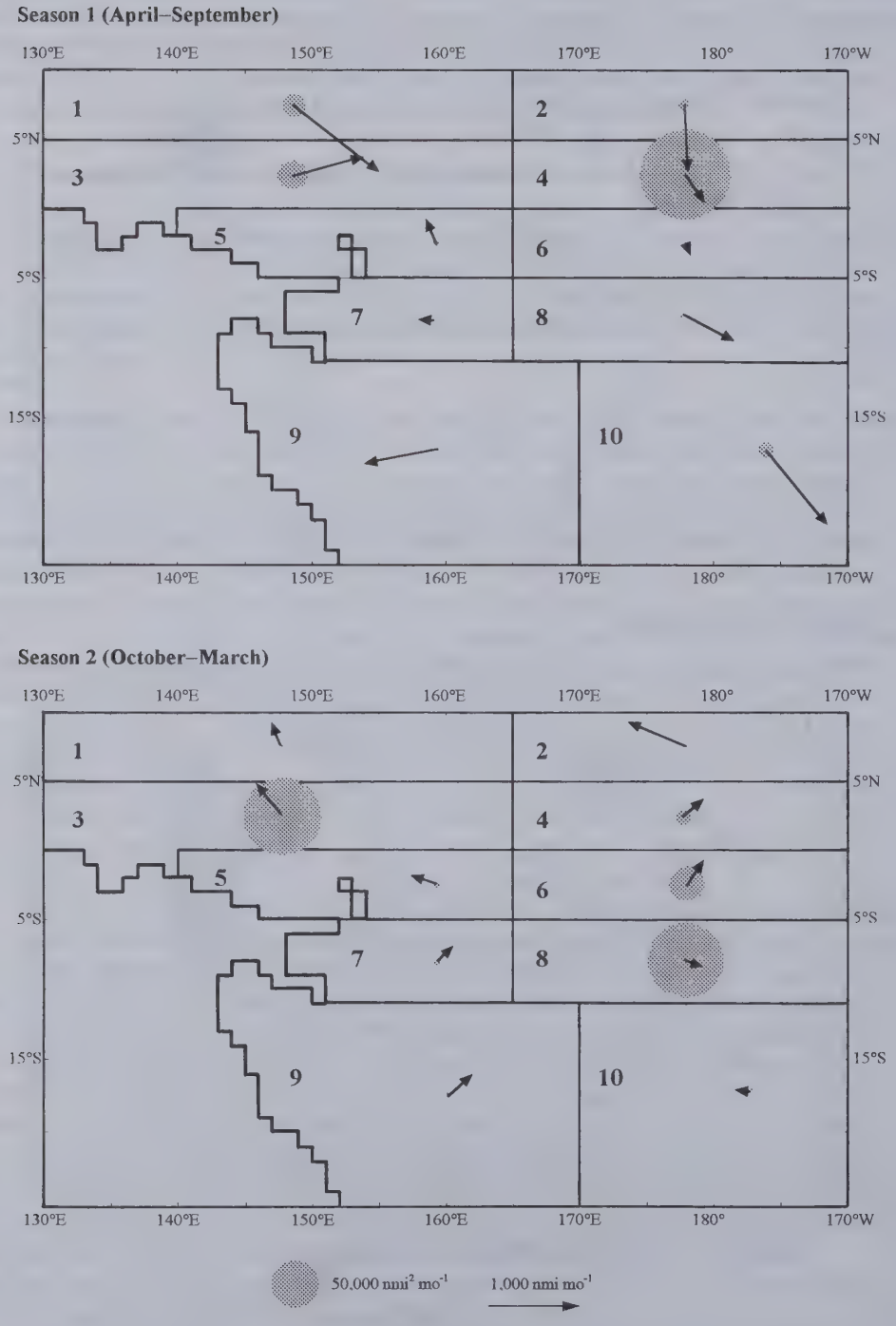

Figure 15. Graphical representation of estimated movement parameters for fit 2 (M=0.05 mo^{-1}). The arrows represent advection and the circles represent diffusion.

Table 17. Parameter estimates obtained from fit 1 of the spatial model to the RTTP skipjack data set. PL and PS refer to pole-and-line and purse seine, respectively. Movement parameters u and v refer to movement in the x and y directions (in degrees per month); σ is the diffusion rate in nm^2 per month.

Natural mortality rate ($mo.^{-1}$)	0.1 (fixed)			
Catchability coefficients	Fiji PL	0.007197	Philippines PS	0.007857
	Japan PL	0.000801	Solomons PL	0.000692
	Japan PS	0.021026	Solomons PS	0.019788
	Kiribati PL	0.001752	Taiwan PS	0.009310
	Korea PS	0.039126	USA PS	0.012587
Movement parameters	u	v	σ	
Season 1 (Apr–Sept)				
Region 1	18.9542	-16.8083	21748	
Region 2	-2.4775	-18.9461	13165	
Region 3	19.0999	5.6958	31502	
Region 4	3.2057	-9.3385	96298	
Region 5	1.0865	7.8533	7139	
Region 6	0.1332	-1.4003	3027	
Region 7	-1.0603	0.0452	1627	
Region 8	10.3506	0.0582	8940	
Region 9	-16.5674	1.6079	2535	
Region 10	-8.3189	12.1047	36806	
Season 2 (Oct-Mar)				
Region 1	-3.5820	1.9146	2371	
Region 2	-13.6989	5.7517	2476	
Region 3	-3.7698	5.5672	82610	
Region 4	6.4508	3.2039	38357	
Region 5	-4.9856	2.7107	6153	
Region 6	6.1796	14.6270	97357	
Region 7	0.9635	0.4823	4501	
Region 8	5.4282	11.4130	81106	
Region 9	18.9628	5.5972	11489	
Region 10	-0.2096	0.0078	1379	

It is clear that estimates of local exploitation rates and other aspects of the tuna's population dynamics are required to more fully understand the interaction questions addressed in this study. We have made a first attempt to do this by developing population dynamics models for skipjack and yellowfin based on tagging data. Spatially aggregated models for the Gilbert Islands area indicated low to moderate impacts of recent purse seine catches in this area on average skipjack ($\sim$7%) and yellowfin ($\sim$3%) catch rates by the TML pole-and-line and artisanal troll fleets. However, these models were not particularly satisfactory, probably because of the lack of spatial structure and assumptions regarding mixing of tagged fish. We therefore developed a spatial model for a large area of the western and central Pacific at one-degree square spatial resolution and applied it to skipjack tagging data. Biomass simulations based on the estimated parameters gave slightly higher ($\sim$10–12%) estimates of the impact of recent purse seine catches at a regional level on average skipjack catch rates by the TML pole-and-line fleet.

Table 18. Parameter estimates obtained from fit 2 of the spatial model to the RTTP skipjack data set. PL and PS refer to pole-and-line and purse seine, respectively. Movement parameters u and v refer to movement in the x and y directions (in degrees per month); σ is the diffusion rate in nm^2 per month.

Natural mortality rate ($mo.^{-1}$)	0.05 (fixed)			
Catchability coefficients	Fiji PL	0.006668	Philippines PS	0.006581
	Japan PL	0.000718	Solomons PL	0.000633
	Japan PS	0.016167	Solomons PS	0.018121
	Kiribati PL	0.001539	Taiwan PS	0.010999
	Korea PS	0.041546	USA PS	0.009155
Movement parameters	u	v	σ	
Season 1 (Apr–Sept)				
Region 1	18.9495	-16.0937	23992	
Region 2	0.0902	-15.6285	10232	
Region 3	19.0859	5.3825	30467	
Region 4	7.5674	-10.2749	97397	
Region 5	-0.1753	8.0505	4606	
Region 6	0.8884	-4.0870	2569	
Region 7	-0.9840	0.0691	1677	
Region 8	10.9593	-6.1599	2522	
Region 9	-14.6596	-1.2416	2577	
Region 10	12.5894	-18.9527	15600	
Season 2 (Oct-Mar)				
Region 1	-1.4299	3.3663	2305	
Region 2	-13.1786	6.5233	2492	
Region 3	-4.7377	6.7455	85609	
Region 4	6.3973	4.4328	14358	
Region 5	-5.6364	3.5791	5811	
Region 6	4.5752	6.9757	37591	
Region 7	1.9005	1.6480	4098	
Region 8	2.3094	-0.2976	87738	
Region 9	4.9776	1.9435	4132	
Region 10	-0.1432	0.0044	1380	

These results should be considered preliminary, as many enhancements to the spatial model are possible, including: expansion of the model area to better represent the biological range of the stock; use of environmental data to parameterise movement and possibly catchability; and the inclusion of catch data into the estimation procedure to hopefully provide better determination of some parameters. Also, the tendency of the model to estimate near-zero values of M for the skipjack data set requires further investigation. The parameter M is an important determinant of interaction – this is clear from the differences in estimated interaction between fits 1 and 2 in this paper and that estimated in Sibert et al. (1996), which used the model estimate of M. If M for skipjack is in fact lower than the value of 0.05 mo^{-1} assumed in fit 2 (which is unlikely given other information on skipjack biology), the interaction levels reported here may be under-estimates. These matters are the subject of ongoing research.

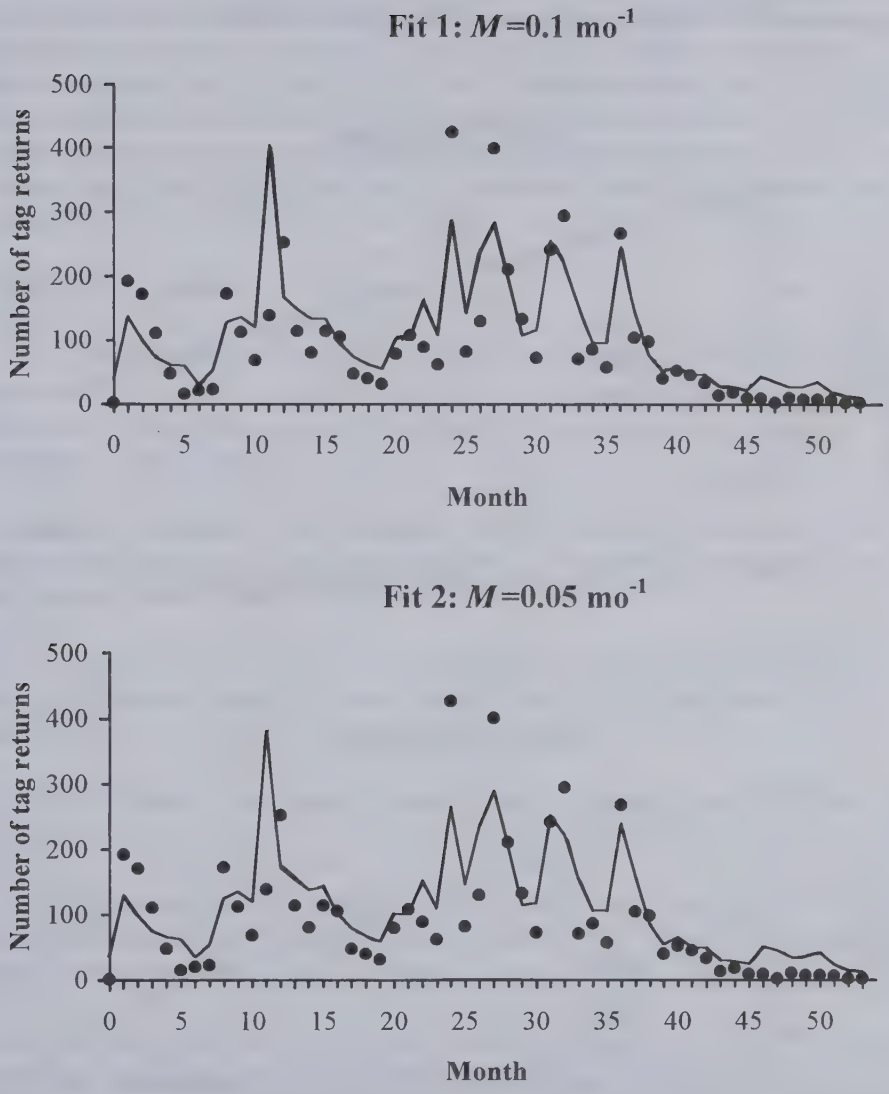

Figure 16. Observed (dots) and predicted (line) tag returns by month of recapture aggregated over the whole model area. Month 0 is July 1989.

The estimates of interaction derived from the analyses of tagging data represent average, long-term expected impacts. It is reasonable to expect that there would be substantial variation in the actual impact over time and at particular locations. This is suggested by the monthly distributions of estimated fishing mortality obtained from the high-resolution spatial analysis; very high local fishing mortality occurs in some 1° squares in some months. This is consistent with the results of the correlation analysis in suggesting that adverse impacts of purse seine fishing on artisanal and pole-and-line catches in the Gilbert Islands are more likely to occur at a very small scale (1° square or less) due to local concentrations of purse seine effort, rather than at a regional scale or on a scale of tens of degrees. The obvious remedy to the small-scale

problem would be to exclude purse seining within, say, 60 nm from the areas fished by the artisanal and pole-and-line fleets. However, the costs of such actions (due to possibly reduced access fees) should be carefully weighed against the potential benefits.

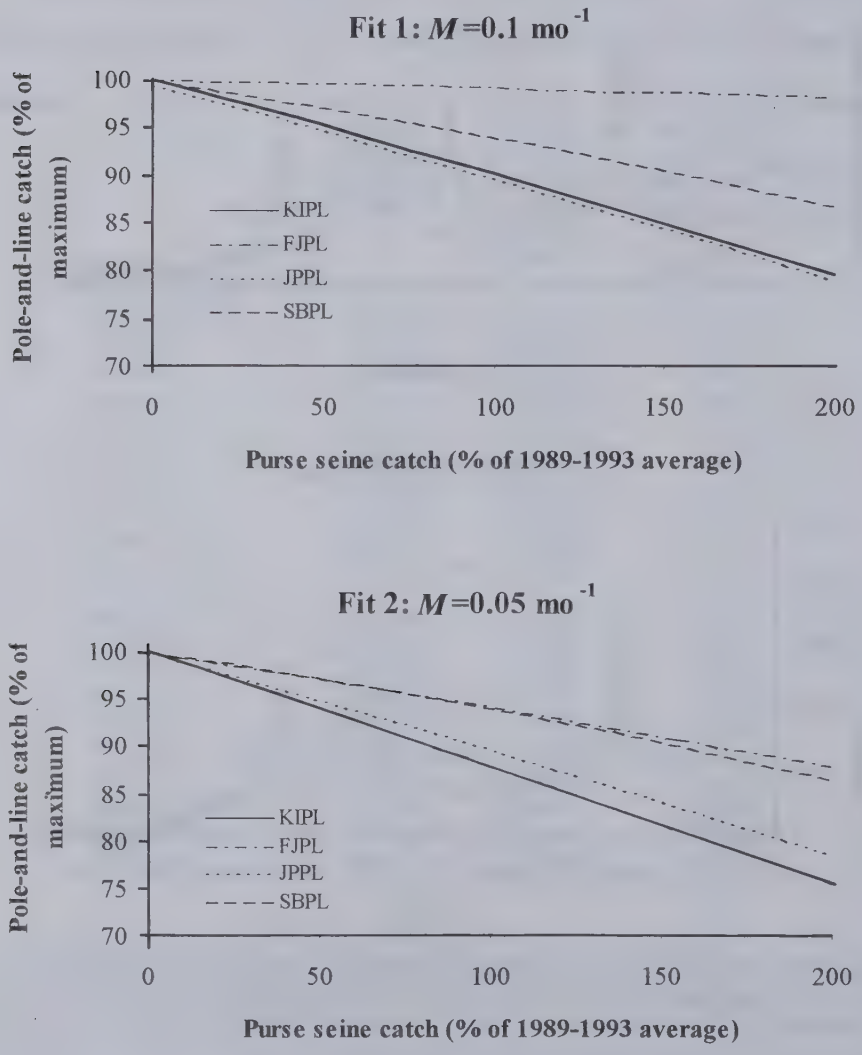

Figure 17. The average effect of various levels of western and central Pacific purse seine skipjack catch on catches by the Kiribati (KIPL), Fiji (FJPL), Japan (JPPL), and Solomon Islands (SBPL) pole-and-line fleets.

The possibility of changes in movement patterns resulting from changes in environmental conditions was raised earlier. The inclusion of various environmental data into the estimation and simulation models as determinants of movement and catchability, as foreshadowed above, would be one way to address this question. However, it is possible that some of the tuna movement characteristics that are important determinants of the extent of fishery interaction in

the Gilbert Islands area occur at a spatial scale even smaller than the one-degree square scale used in the spatial model applied here. It is possible, for example, that the aggregational effects on tuna of the islands and banks fished by Kiribati fishermen are important in determining the level of interaction with purse seine vessels operating in the near vicinity. Such effects, if they exist, have been ignored in the models applied here. A possible extension of this work, given adequate data, would therefore be to apply a very-fine-scale spatial model of the Gilbert Islands area (possibly at half-degree square resolution or finer), incorporating parameters to describe the effects of islands and banks on tuna movement. A similar model has been applied to the Solomon Islands area (Kleiber and Hampton, 1994).

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DO LOCAL CATCHES AFFECT LOCAL ABUNDANCE? TIME SERIES ANALYSIS ON HAWAII'S TUNA FISHERIES

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ABSTRACT

Bigeye tuna (*Thunnus obesus*) and yellowfin tuna (*T. albacares*) are important in several fisheries that operate within the Hawaii exclusive economic zone (EEZ). These species are believed to be widely distributed across the Pacific Ocean, and the strong seasonality of catch rates suggests extensive exchange of fish between the Hawaii EEZ and other regions. Nevertheless, Hawaii fishermen and fishery managers have concerns that local catches could reach levels high enough to depress local fish abundance.

Time series analysis was used to test the null hypothesis that local catches had no effects on local abundance in the Hawaii EEZ from 1962 to 1992. Transfer function models were used in the analysis with local catches as the input variables and catch per unit effort (CPUE) indices from the Hawaii domestic handline, longline, and troll fisheries as the output variables. Time series of both catch and CPUE were differenced to remove long-term trends and seasonality before the analysis. The predominant significant findings were positive relationships between catch and CPUE at the monthly time scale and zero lag, for both species and all fisheries. Catches increased when CPUE was increased, and decreased when CPUE decreased. Few negative relationships were found at any lags. The analysis showed no significant negative effects of catches on CPUE for bigeye tuna at an annual time scale. A barely significant negative effect on longline CPUE was found at the monthly time scale at a lag of two months. For yellowfin tuna, a barely significant negative effect on longline CPUE was found at the annual time scale at a lag of one year. Model forecasts were made for 1993 and 1994 and compared with preliminary 1993 data.

1. INTRODUCTION

Bigeye tuna (*Thunnus obesus*) and yellowfin tuna (*Thunnus albacares*) are targeted by several of Hawaii's commercial fisheries, and yellowfin tuna are also targeted by the recreational fishery. Catches of these two species have composed an important fraction of Hawaii's total fish catch since the development of the Hawaii longline fishery in the 1920s and the expansion of the small-vessel troll and handline fisheries in the 1970s (Boggs and

Ito, 1993). However, studies on the effects of local catches on local abundance of both species have been few for two reasons. First, only small fractions of what are thought to be widely distributed stocks are seasonally available to Hawaii fisheries, so local catches should have little effect on overall population abundance (Suzuki, 1993; Miyabe 1993; Skillman et al., 1993). Second, tunas were not included as pelagic management unit species until the Magnuson Act was amended in 1991 and the pelagic fishery management plan was amended by the Western Pacific Regional Fishery Management Council (WPRFMC) in 1992 (Federal Register, vol. 57, p. 48564). Recently, rapid expansion of the Hawaii longline fishery has caused concern about whether local depletion of both species can occur at short temporal scales (Boggs and Ito, 1993; Boggs, 1994). Gear conflicts between longliners and fishermen using troll and handline gears were also a problem. These concerns prompted the federal fisheries management authority (the WPRFMC) to develop several regulations for Hawaii fisheries that include limits on the numbers and size of longline vessels and closure of coastal areas to longline fishing (Pooley, 1993).

We evaluated effects of total catches of bigeye tuna and yellowfin tuna on local abundance within the Exclusive Economic Zone (EEZ) of the main Hawaiian Islands by applying time series models to long-term fisheries catch data. Catch per unit effort (CPUE) was used as an index of apparent local abundance. We hypothesized that local catches had no effects on local abundance of yellowfin tuna and bigeye tuna. We tested the hypothesis with time series models that used combined local catches by domestic and foreign fisheries as input variables and domestic CPUE values as output variables. For each model, if the parameters relating catch to CPUE were not significantly negative, we did not reject the null hypothesis that catches had no effects on CPUE and inferred that local fisheries may not affect local abundance of fish. We used time series data at two temporal scales (monthly and annual) to test the hypothesis.

Should be combined with distribution data cause there could be shrinkage

2. METHODS AND MATERIALS

2.1 Time Series Models

We used transfer function models in this analysis (Wei, 1990; Bowerman and O'Connell, 1993; Carpenter, 1993). Transfer functions can be viewed as relationships between anomalies of input and output variables. The anomalies are the remaining time series after serial dependencies and seasonal trends in the original series are removed by ARIMA models (Autoregressive Integrated Moving Average models, Wei, 1990). If anomalies in the output variable are not explainable by their own series dependency or seasonality but follow anomalies in the input variable, then there exist relationships between the input and output variables, and a transfer function can be fit.

The general form of the simplified linear transfer function can be represented as

$$y_t = \omega_s(B)\, x_{(t-b)} + \eta_t \qquad (1)$$

where t is time, y is the time series for the output variable, x is the time series for the input variable, b is a delay parameter representing the actual time lag that elapses before the

input variable produces an effect on the output variable, η is the residual model for y_t (see Equation 3), $\omega_s(B)$ are parameters of the transfer function that represents effects of the input variable extended to s time units in the past on the current value of the output variable, and B is the backshift operator often used in time series models with the property that $B^b Z_t = Z_{t-b}$ (where Z is any variable). $\omega_s(B)$ can be written as

$$\omega_s(B) = \omega_0 + \omega_1 B^1 + \ldots + \omega_s B^s \qquad (2)$$

The residual model for y_t, η_t, can be written as

$$\eta_t = \frac{(1 - \phi_1 B - \ldots - \phi_p B^p)\, a_t}{(1 - \theta_1 B - \ldots - \theta_q B^q)} \qquad (3)$$

where the numerator describes a moving average (MA) process while the denominator describes an autoregressive (AR) process, a_t is a zero mean white noise process, and ϕ_p and θ_q are parameters representing an MA process at order of p and an AR process at order of q, respectively (Wei, 1990). When the transfer function models were used for the monthly time series analysis, a second factor that represents the seasonality of 12 months was included in both the MA and AR processes. The residual model can then be written as

$$\eta_t = \frac{(1 - \phi_1 B - \ldots - \phi_p B^p)\,(1 - \phi_{12} B^{12})\, a_t}{(1 - \theta_1 B - \ldots - \theta_q B^q)\,(1 - \theta_{12} B^{12})} \qquad (4)$$

In our models, the input variables (x_t) were total catches by all gears in the Hawaii fisheries and the output variables (y_t) were CPUE values, which were assumed to be representative of the relative local abundance of fish. Because the transfer function models require time series to be stationary but both total catch and CPUE were not, all time series data were differenced in the model. That is

$$x_t = x_t - x_{t-d} \qquad (5)$$

and

$$y_t = y_t - y_{t-d} \qquad (6)$$

where d is some time unit in the past. When time series data were at the annual scale, $d=1$, and while at the monthly scale, $d=12$. Detrending the annual time series by differencing removes effects of long-term trends such as increases in catchability due to technology or expertise. However, short-term environmental effects on the detrended series could still remain. Detrending the monthly time series not only makes the time series into a stationary series but also removes the seasonality from the time series (Cohen and Stone, 1987; Wei, 1990).

Data from 1962-1992 were used to build the transfer function models (see next section for details), resulting in 31 data points at the annual and 372 at the monthly time scale. Construction of all transfer function models and estimates of all parameters were done using the SAS statistics program, version 6.09 (SAS Institute, Inc., 1993). Detailed procedures on construction of models and estimation of parameters can be found in Wei (1990), Bowerman and O'Connell (1993), and SAS Institute, Inc. (1993). In some situations several models with different parameter values provided significant fits to the same data. These models were presented and compared based on the goodness-of-fit of the models. If no lag terms were significant, the model with $b=0$ and $s=0$ was presented.

After the models were fit, the best model for each species was used to forecast 1993 CPUEs using preliminary 1993 catch data. Estimated 1993 CPUEs were compared with the observed CPUEs. These comparisons were useful to validate the models. For 1994, both total catches and CPUEs were forecasted, again using the procedures in Bowerman and O'Connell (1993) and SAS Institute, Inc. (1993).

2.2 Data Sources

Three sets of fisheries data were used in this paper: (1) domestic total catch in kg from all gears used by the Hawaii domestic fisheries as reported to the Hawaii Department of Aquatic Resources (HDAR) from 1962 to 1992; (2) foreign longline catch by Japanese fishing vessels in the EEZ of the main Hawaiian Islands (Yong and Wetherall, 1980); (3) CPUE from the Hawaii domestic handline, longline, and trolling fisheries derived from the HDAR data for 1962 to 1992, hereafter referred to as CPUE. Total catch was calculated by summing domestic and foreign catches.

Previous studies (Hudgins and Pooley, 1987) reported that total catches from the HDAR data sets underestimated actual catches because some fishermen, especially longliners, failed to report their catches. To solve this problem, we compared HDAR catch data for various gears and ports of landing with data from fish dealers in the Hawaiian Islands (Pooley, NMFS, Honolulu, Hawaii, unpubl. data). Catches from the HDAR data sets were similar to the dealers' data for handline and trolling gears but were much lower than the dealers' data for longline gear, especially from the early to mid 1980s. We then calculated annual raising factors for longline gear based on the comparisons between the HDAR data and the dealers' data. Final estimates of total catches by the local fisheries used in this paper were then calculated from raised HDAR longline data plus the HDAR data for all other gears. Details on the estimation of these raising factors will be described in a separate report (Boggs, He, Yang and Curran, NMFS, Honolulu, Hawaii, unpubl. data).

Domestic longliners have extended their range beyond the Hawaii EEZ, especially as they began targeting swordfish (*Xiphias gladius*) during 1990-92. No correction of the domestic catch data was made for fish caught outside the EEZ. Domestic longliners that targeted tuna fished primarily within the EEZ during 1990-92.

Longliners from Japan were active in the Hawaii EEZ prior to April of 1980 after which, under new regulations, they chose not to fish. Total catches by Japan in the Hawaii EEZ from 1962 to April of 1980 were estimated using the same procedures as Yong and

Wetherall (1980). These procedures included converting numbers of fish to weight using average weight statistics from Hawaii longline catches.

The CPUEs of both species were obtained from the HDAR data. Longline CPUEs were calculated as kg per trip and converted to kg per 1,000 hooks as described below. The CPUEs for the handline and troll fisheries were calculated as kg per trip. For bigeye tuna, because reported catches by handline and trolling were very low, only CPUEs from the longline fishery were calculated.

To calculate CPUE from the HDAR data, certain problematic records were first deleted. The following six procedures were applied:

(1) Incomplete records, such those with missing date, species names, type of gear, etc., were deleted.
(2) Records from trips that used more than one fishing gear on a trip were deleted.
(3) Records that reported no catch of any species were deleted because such data were not consistently recorded before 1990.
(4) Records of handliners who fished at offshore seamount and weather buoy areas from 1989 to 1992 were deleted because the offshore handline fishery is distinct, and including these data in the analysis would bias the long-term trend of CPUE time series.
(5) Records of longliners from trips whose reporting intervals (presumably lengths of trip) were ≤ 3 days were deleted. These data probably represent landing over several days from single trips, or a group of longliners that conduct very short trips.
(6) Records of longliners from trips that presumably targeted swordfish (*Xiphias gladius*) from 1990 to 1992 were deleted. Identification of swordfish trips was done by applying cluster analysis on species composition data (% of total catch) from each trip. All trips that belonged to the cluster with the highest catch of swordfish were then deleted.

Because the HDAR data only provided total catch per trip, to convert longline CPUE to weight per 1000 hooks, the annual average numbers of hooks used per longline trip were estimated from other data sources (Boggs and Hawn, NMFS, Honolulu, Hawaii, unpubl. data).

3. RESULTS

3.1 Bigeye Tuna

At the annual time scale, total catches of bigeye tuna by all gears fluctuated around 1,000 mt from 1962 to late 1970s (Figure 1). Total catches then dramatically declined from 1,504 mt in 1978 to 82 mt in 1981. Beginning in 1982, total catches steadily increased to around 1,700 mt in the early 1990s. The annual longline CPUE of bigeye tuna, however, showed a different pattern. CPUEs were the highest in the 1960s, fluctuating around 350 kg per 1,000 hooks, and then decreased to around 150 kg per 1,000 hooks in 1970s (Figure 1). Corresponding to the lowest total catch (all gears) in 1981, longline CPUE was zero in 1981. These longline data may reflect an unresolved under-

reporting problem. From 1982 to 1992, CPUEs fluctuated around 120 kg per 1,000 hooks.

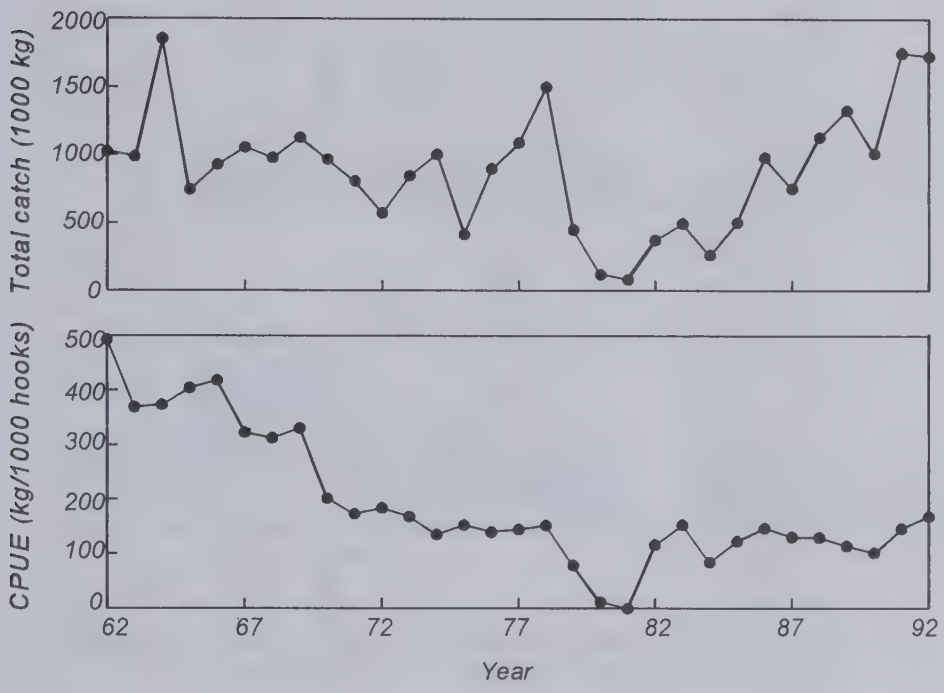

Figure 1. Annual total catch and catch per unit effort (CPUE) for bigeye tuna caught by the Hawaii longline fishery from 1962 to 1992.

At the annual time scale, time series analysis indicated that total catches had no negative effects on CPUE. In other words, we found no evidence that CPUE was lower when catch was higher, at any lag. Instead, ω terms in models (Table 1) indicated significant positive relationships between total catches and CPUE. Note that for example, Model 3, which included each of the lag terms found to be significant in Models 1 and 2, and fitted the data best, showed positive relationships at lags of 0 years (ω_0=0.000048) and at 5 years (ω_5=0.000051). In other words, when catch was higher, CPUE was higher during that year and 5 years later.

At the monthly time scale, both total catches and CPUE of bigeye tuna showed strong seasonality in all years except during the early 1980s when both catches and CPUE were the lowest (Figure 2). In general, high catches and CPUE occurred during the winter months; and within-year variability (i.e., seasonal change) was greater than between-year variability (i.e., annual change).

At the monthly time scale, time series analysis showed that total catches had a positive relationship with CPUE at a lag of 0 months (ω_0=0.00040, Model 1 in Table 1) and had a negative effect on CPUE at a lag of 2 months in another model with only slightly better fit (ω_2=-0.00020, Model 2 in Table 1).

Table 1. Parameter estimates of transfer functions relating total catches to catch per unit effort (CPUE) and residual models for bigeye tuna at annual and monthly time scales from 1962 to 1992. The input variable is total catch and the output variable is CPUE for the Hawaii longline fishery. Abbreviations are: b= delay parameter (see Equation 1); s.e. = standard error for the estimate; T ratio = T statistics for the estimate (|T ratio| > 1.96 indicates the estimate is significantly greater than zero with probability of 0.95); SBC = Schwartz's Bayesian Criterion, which measures goodness-of-fit. The smaller the value of SBC, the better the fit.

Model	Transfer function					Residual model	SBC
	b	Term	Estimate	s.e.	T ratio	Order and estimate	
Annual scale							
Model 1	0	ω_0	0.000041	0.000018	2.29	AR: $1-0.49B^2$	319
Model 2	5	ω_0	0.000059	0.000018	3.25	None	257
Model 3	0	ω_0	0.000048	0.000019	2.50		
		ω_5	0.000051	0.000017	3.02	None	254
Monthly scale							
Model 1	0	ω_0	0.00038	0.000076	5.02	AR: $1-0.74B^1$	
						MA: $(1-0.32B^1+0.18B^{11})(1-0.78B^{12})$	4360
Model 2	0	ω_0	0.00040	0.000075	5.31		
		ω_2	-0.00020	0.000075	-2.68	AR: $1-0.75B^1$	
						MA: $(1-0.33B^1+0.20B^{11})(1-0.79B^{12})$	4335

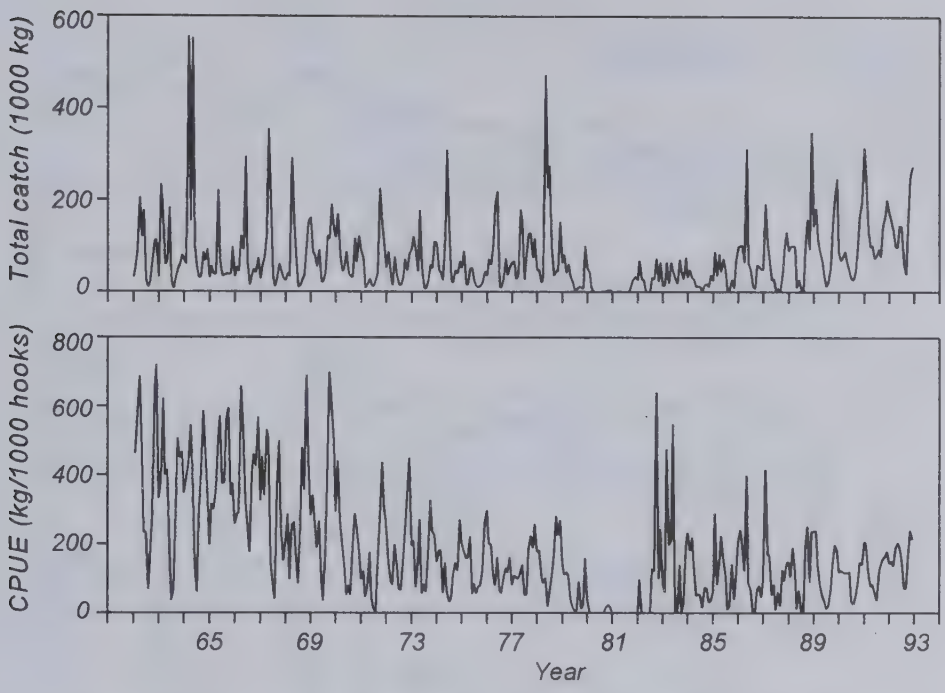

Figure 2. Monthly total catch and catch per unit effort (CPUE) for bigeye tuna caught by the Hawaii longline fishery from 1962 to 1992.

3.2 Yellowfin Tuna

At the annual time scale, total catches of yellowfin tuna steadily increased from around 300 mt in the early 1960s to around 1,600 mt in the early 1990s with a peak of 2,265 mt in 1986 (Figure 3). The CPUE for handline gear showed an increasing trend similar to the total catch but with a peak in 1978 (Figure 3). The CPUE for both longline and trolling gears, however, showed different patterns from that of handline gear (Figure 3). The CPUE for longline gear fluctuated around 100 kg per 1,000 hooks prior to 1980 and fluctuated around 70 kg per 1,000 hooks after 1982. Longline CPUE had the highest CPUE values in 1970 and 1980. The CPUE for trolling gears was low from the 1960s to the early 1970s, high in the mid 1970s with a peak in 1978, and then deceased thereafter (Figure 3). The CPUE for trolling gear in the most recent years (1987 to 1992) was low and similar to the CPUE from the 1960s to the early 1970s.

At the annual time scale, time series analysis showed that total catches of yellowfin tuna had no effects on handline or trolling CPUE at any lags, since estimates of ω were not significant (Table 2). However, total catches of yellowfin tuna had a positive relationship with longline CPUE at a lag of 0 years (ω_0=0.00012) and had negative effects at a lag of 1 year (ω_1=-0.000075) in Model 2 (Table 2).

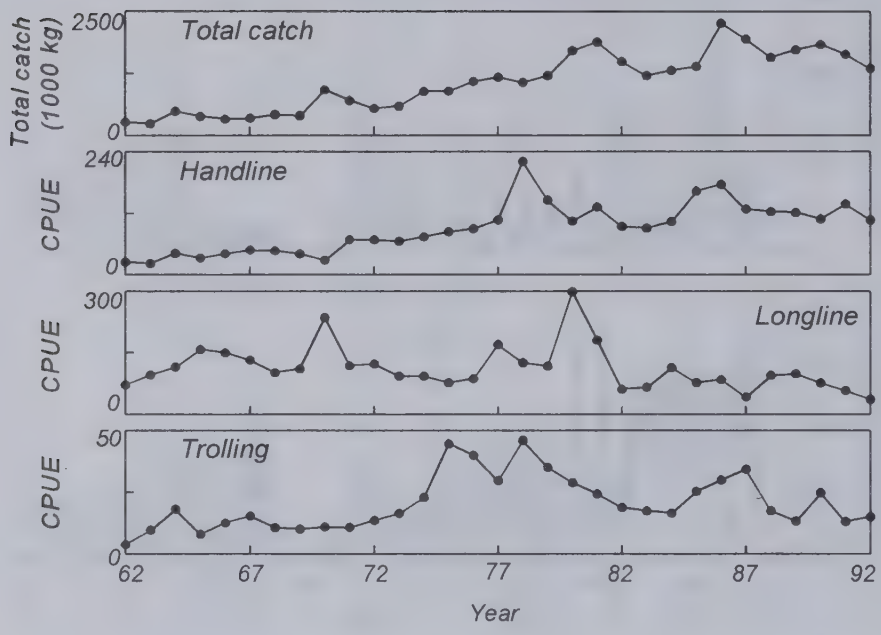

Figure 3. Annual total catch and catch per unit effort (CPUE) for yellowfin tuna caught by the Hawaii handline, longline, and trolling fisheries from 1962 to 1992.

At the monthly time scale, time series of total yellowfin tuna catches and CPUE for three gears (Figure 4) showed similar patterns as those for bigeye tuna: strong seasonality with higher within-year variability than between-year variability. The differences between the bigeye and yellowfin tuna times series were that high catches and high CPUEs for yellowfin tuna occurred during the summer months instead of the winter months.

At the monthly time scale, time series analysis showed that total catches of yellowfin tuna had positive relationships with the CPUEs of all three gears at lag of 0 months, as all estimates of ω_0 were significantly positive (Table 2).

3.3 Comparisons of Observed, Estimated and Forecasted CPUE

The time series of estimated CPUE (1985-92), CPUE forecasted by the transfer model (1993-94), observed CPUE for bigeye tuna caught by longline (1985 to 1992), and preliminary data for 1993 (Figure 5) showed that the estimated CPUE matched well with the observed CPUE, especially in terms of seasonal changes. In other words, the model was good at estimating when the peaks of CPUE should occur. In 1993, the CPUE forecasted using the total catch data showed similar seasonal changes, but failed to estimate an atypical peak in CPUE observed from June to August (Section B, Figure 5). The CPUE forecasted for 1994 without having total catch data showed the same seasonal changes as were estimated for 1993.

Table 2. Parameter estimates of transfer functions relating total catch to catch per unit effort (CPUE) and residual models for yellowfin tuna at annual and monthly time scales from 1962 to 1992. The input variables are total catches and the output variables are CPUE for handline, longline, and trolling, respectively. Abbreviations are same as in Table 1.

Model	Transfer function					Residual model	SBC
	b	Term	Estimate	s.e.	T ratio	Order and estimate	
Annual scale, handline							
Model 1	0	ω_0	0.0000042	0.0000022	0.19	None	---
Annual scale, longline							
Model 1	0	ω_0	0.00011	0.000038	2.91	AR: $1+0.18B^2$	328
Model 2	0	ω_0	0.00012	0.000028	4.33		
		ω_1	-0.000075	0.000027	-2.72	AR: $1+0.33B^2+0.41B^6$	315
Annual scale, trolling							
Model 1	0	ω_0	-0.000094	0.000055	-1.70	None	
Monthly scale, handline							
Model 1	0	ω_0	0.00049	0.000047	10.40	AR: $1-0.54B^1$	
						MA: $(1+0.19B^{11})(1-0.94B^{12})$	---
Monthly scale, longline							
Model 1	0	ω_0	0.00072	0.00011	6.84	AR: $1-0.77B^1$	
						MA: $(1-0.45B^1+0.23B^7)(1-0.76B^{12})$	---
Monthly scale, trolling							
Model 1	0	ω_0	0.00054	0.00012	4.38	AR: $1-0.87B^1$	---
						MA: $(1-0.38B^1-0.18B^2+0.21B^{10})(1-0.82B^{12})$	

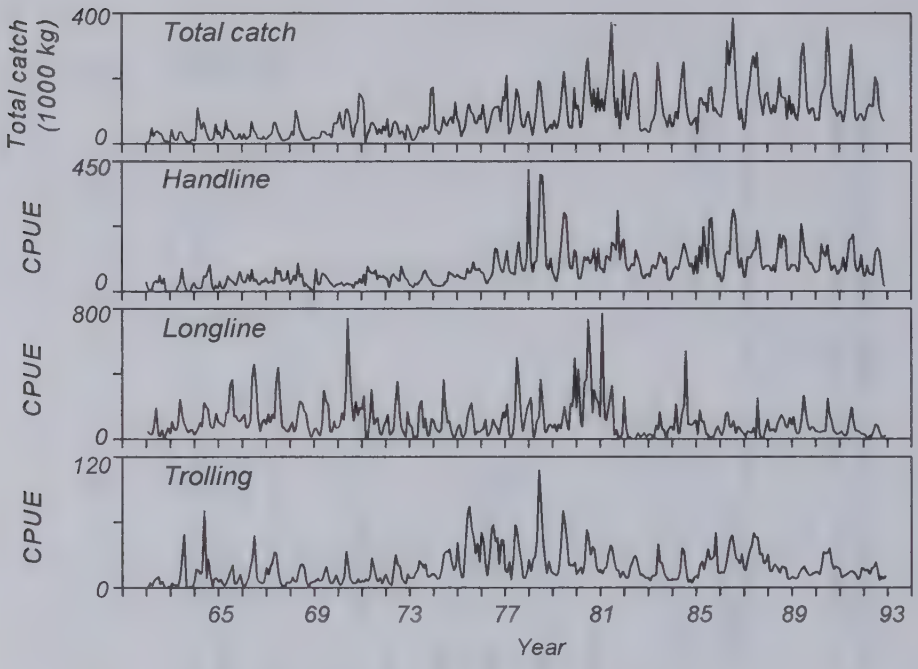

Figure 4. Monthly total catch and catch per unit effort (CPUE) for yellowfin tuna caught by the Hawaii handline, longline, and trolling fisheries from 1962 to 1992.

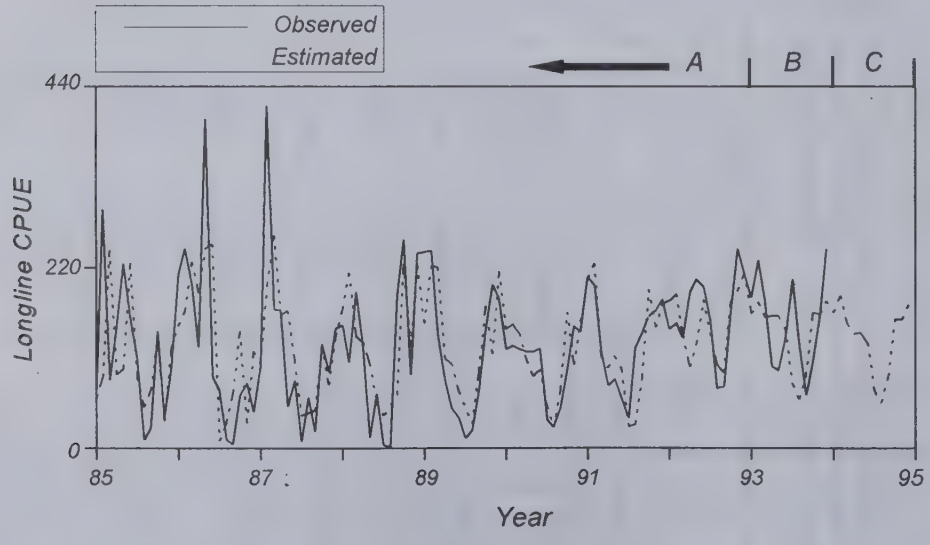

Figure 5. Monthly observed catch per unit effort (CPUE) for bigeye tuna caught by the Hawaii longline fishery from 1962 to 1992 (solid line, Section A and B), estimated CPUE from 1962 to 1992 (dashed line, Section A), forecasted CPUE using the input variable (total catch) in 1993 (dashed line, Section B), and CPUE forecasted without the input variable (dashed line, Section C).

Comparison of the time series of estimated and forecasted CPUE from the transfer models with the observed CPUE for yellowfin tuna caught by three gears (handline, longline, and trolling, Figure 6) generally showed that the estimates matched fairly well with the observed CPUE, especially for handline gear (Section A, Figure 6). Similar to the longline CPUE model for bigeye tuna, the three yellowfin tuna models estimated the seasonal changes well. Among the three gears, the estimated CPUE for handline matched best with the observed CPUE. The 1993-94 forecasted CPUE of three gears showed similar seasonal changes.

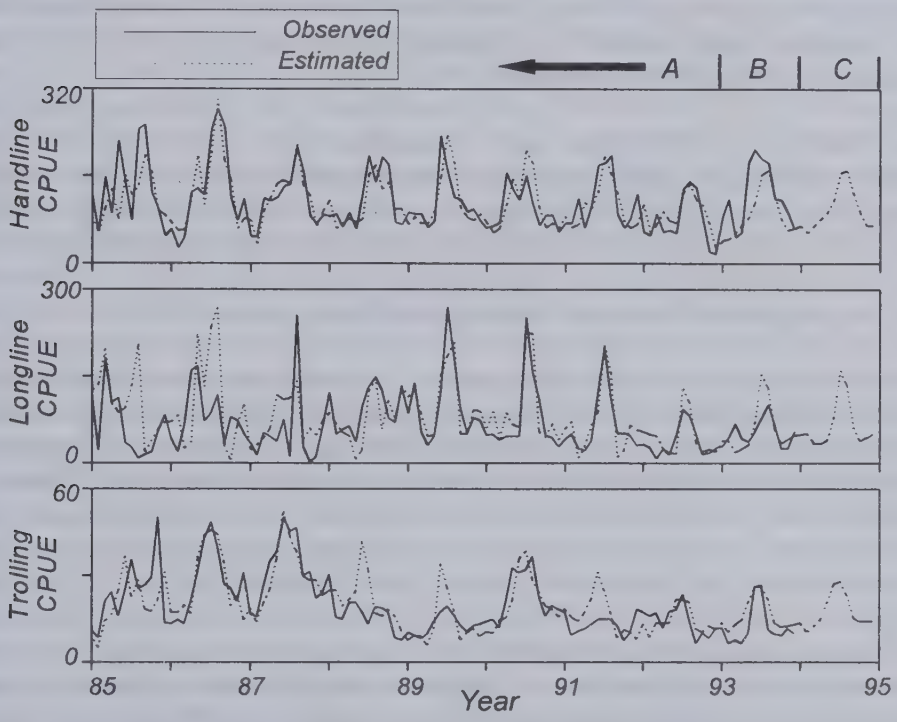

Figure 6. Monthly observed catch per unit effort (CPUE) for yellowfin tuna caught by the Hawaii handline (top panel), longline (middle panel), and trolling (bottom panel) fisheries from 1962 to 1992 (solid line, Section A and B), estimated CPUE from 1962 to 1992 (dashed line, Section A), forecasted CPUE using the input variable (total catch) in 1993 (dashed line, Section B), and CPUE forecasted without the input variable (Section C).

4. DISCUSSION

This paper addresses a question that has become a major concern of fishermen and management agencies in Hawaii: Do local catches affect local abundance of bigeye and yellowfin tuna? Prior to the inclusion of tunas in the US domestic fishery management regulations, similar questions were the subject of studies on managed species such as blue and striped marlin (Boggs, 1994). From the fisheries science viewpoint, these are not easy questions to answer. Rigorous answers require knowledge of exploited stock parameters such as catchability, availability, recruitment, natural mortality, and fishing mortality.

Adequate estimation of such parameters may be very difficult or prohibitively expensive. Furthermore, the issue becomes much more complex as the stocks of both species are thought to be widely distributed. As Boggs (1994) pointed out, the troll CPUE of yellowfin tuna in Hawaii appeared not to be affected by domestic catches of yellowfin tuna, but was directly related to the apparent abundance of yellowfin tuna over a wide area of the central-western Pacific.

At present, information on stocks and movement patterns of both species around the Hawaiian Islands is not available, and will not likely be available in the near future. The best available data relevant to the question are long time series of Hawaii commercial fisheries statistics reported to HDAR. These may be inadequate to determine population parameters or true local abundance but we contend that they are useful for addressing the empirical question: Do local catches affect local CPUE?

The reliability of the HDAR data has been questioned by researchers and others aware of missing or inconsistent reports, misidentification of species, recording errors, and lack of data on unsuccessful trips. This analysis is a preliminary product of a project designed to intensively analyse the HDAR data and to account for problems with that data set. Our philosophy echoes the USA's federal management policy of using the best available data and our goal was to pose hypotheses that can be tested using the HDAR data.

The preliminary finding of this study is that we did not reject the null hypothesis that local catches have no effects on local abundance of both species. When fishing mortality is effectively reducing fish biomass, there should exist a negative relationship between catch and CPUE (Hilborn and Walters, 1992). However, we found no pattern of negative relationships. The positive relationships between catch and CPUE observed at the monthly time scale and zero lag for all fisheries does not imply that increasing catch *caused* CPUE to increase.

Positive relationships between catch and CPUE could result from lack of independence between catch and CPUE if both are calculated from the same data. We did not expect this to be the case in our analysis because we did not use same data to calculate both variables. Catch was the total from all domestic and foreign fisheries combined, whereas CPUE was calculated for individual domestic fisheries using a qualified subset of the data.

The two significant negative relationships found between local catches and CPUEs, one for bigeye tuna longline CPUE at a lag of two months and the other for yellowfin tuna troll CPUE at a lag of one year, did little to improve the fit of the transfer models. Consideration of multiple possible relationships dilutes the significance of these findings, and they do not seem to be part of any overall pattern of negative lag effects.

It is important to note that low CPUEs occurred when catches were low and numbers of fishing trips (presumably representing fishing effort) were low (Boggs and He, NMFS, Honolulu, unpubl. data). Fishermen may fish more when CPUE is higher than normal, and fish less when CPUE is lower than normal. The latter implies that local catches do not affect CPUE because fishing effort is reduced when CPUE declines, tending to prevent depletion of local abundance. A further analysis of fishing effort would be useful.

Catches and fishing effort are highly seasonal and correspond with seasons of high CPUE. For bigeye tuna total fishing effort is dominated by the longline fishery and peaks in winter. For yellowfin tuna total fishing effort is dominated by the troll and handline fisheries and peaks in summer. It remains to be seen if data on total effort would indicate positive correlations between differenced total effort and differenced CPUE. Such an analysis cannot be presented due to unresolved difficulties in quantifying total effort from the different fisheries.

Perhaps the most questionable assumption of this study is that changes in CPUEs represent changes in local fish abundance. Time series of CPUEs used in this study spanned over 30 years. It is undoubted that fishing techniques and fishermen's behaviour changed over this period. Therefore the catchability and fishing efficiency changed. Time series of CPUEs may include trends due to these changes, especially for handline and trolling gears whose CPUEs are measured as catch per fishing trip. At present, we cannot independently estimate these trends and remove them from the time series of CPUEs. What we did, however, was to detrend the time series by differencing, which removed long-term trends of changes in catchability and fishing efficiency together with long term trends in abundance, and emphasized short-term changes in CPUEs.

To remove some of the variations due to different fishing methods, our ongoing project is attempting to use multivariate analysis to cluster fishermen into subgroups based on their catch composition, their fishing expertise, and their fishing behavior. Time series of CPUEs estimated from these subgroups of fishermen will then be compared and used in future time series modelling. We are also attempting to model the damping effect on true variation in CPUE that is caused by the exclusion of data from unsuccessful fishing trips.

We expected that local catch would have, if any, more apparent relationships with local abundance at the monthly time scale than at the annual time scale, as was true for yellowfin tuna for both handline and trolling gears (Table 2). At the annual time scale, there were no significant relationships between catches and CPUEs for both handline and trolling gears, while at the monthly time scale, there existed positive relationships between catches and CPUEs for all gears. The prevalence of relationships at the monthly time scale is probably because (1) both species are thought to be highly mobile and widely distributed, and long-term trends in local abundance (i.e., years to decades) would be strongly affected by exogenous trends in the Pacific-wide stocks; (2) the immigration of fish to the local area appears to be highly seasonal, and strong seasonality in local abundance (i.e., from month to month) might exceed interannual variability; and (3) thus, the annual averages of CPUE would be much less sensitive to catches than the monthly averages of CPUE.

Time series analyses, especially transfer models, have not been commonly used in fisheries research (but see Cohen and Stone, 1987; Fogarty, 1988; Stergiou, 1989; Mendelssohn and Cury, 1989), mainly because time series analyses require long-term and stationary data that are often lacking. Hawaii fishery researchers are fortunate to have the HDAR data, which may have many problems but do contain much useful information on long-term and fine scale changes in Hawaii fisheries. This analysis demonstrates that time series models are applicable to the HDAR data, as shown by fairly good matches between observed and estimated CPUEs for both species and all gears. No useful alternative data are available for evaluating Hawaii troll and handline fisheries, nor are there any other data

or information available for more traditional stock assessment. Time series modeling using HDAR data may be the most valuable tool available for studying Hawaii pelagic fisheries.

Future work will involve not only improving estimates of CPUEs by removing outliers from the data and by modeling distributions of CPUEs (Richards and Schnute, 1992; Perkins and Edwards, 1994), but also applying more advanced time series models, such as nonlinear transfer functions (Wei, 1990), multivariate time series models on multi-species catches (Cohen and Stone, 1987), Bayesian dynamics models that incorporated more recent data and more accurate data (i.e., federally mandated longline log data) (Pole et al., 1994) and spatially explicit time series models (Gillis et al., 1993).

5. ACKNOWLEDGMENTS

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INTERACTIONS OF TUNAS AND BIG PELAGIC FISHES AMONG SPORT AND COMMERCIAL FISHERIES IN MEXICAN WATERS OF THE PACIFIC OCEAN

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ABSTRACT

Sportfishing, baitboat, purse seine, longline and drift gillnet fisheries in Mexico are briefly described in this paper. Regulations applied to these fisheries within Mexican Exclusive Economic Zone are also discussed. Longline and sportfishing interactions for several pelagic finfish species are discussed and potential interactions among the baitboat, purse-seine and sportfishing are pointed out. Future research in critical areas is proposed.

1. INTRODUCTION

The Mexican tuna and billfish fisheries in the Pacific consist of five gear types. They include troll (sportfishing), pole-and-line (baitboat), purse seine, longline and, more recently, drift gillnet.

1.1 Sportfishery

The sportfishery in the west coast of Mexico was initiated in the early 1950s (Ponce-Díaz, 1993). This fishery developed concurrently with development of the tourist industry along the west coast of Mexico. In the early 1980s a number of internationally recognized sportfishing ports were established along the west coast of Mexico. Historical records of Mexico's marine rod-and-reel sportfishery from 1969 to the present have been obtained by postcard surveys conducted by National Marine Fisheries Service (Squire and Muhlia-Melo, 1993). Catch has focussed on the principal billfish species including striped marlin, blue marlin, black marlin and sailfish. Some data on tunas and other big pelagics are also collected. Location of the most important sportfishing areas in the Pacific coast of Mexico include the southern tip of Baja California--Mazatlán, San Blas, Puerto Vallarta, Manzanillo, Ixtapa-Zihuatanejo and Acapulco. A review of the billfish fisheries and resource management by Mexico and the USA in the northeast Pacific Ocean has been presented by Squire and Muhlia-Melo (1993).

1.2 Baitboat and Purse Seine Fisheries

The baitboat fishery was initiated in Mexico in 1937 and reached a high in catches of 3,528 mt in 1965 (Muhlia-Melo 1987). The purse-seine fleet developed in the early 1960s and reached a high in production of 47,926 mt in 1987. Trends of carrying capacity of the purse-seine and baitboat fleets of Mexico from 1985 to 1993 are presented in Table 1.

Table 1. Carrying capacity (mt) of the Mexican tuna fleet in the eastern Pacific Ocean, 1985-93. (Data source: IATTC, 1986, 1987, 1988, 1989, 1991, 1992a, 1992b, 1993, 1994.)

Year	Purse Seine	Baitboat	Total
1985	45,935	1,458	47,393
1986	38,980	1,127	40,107
1987	47,926	1,269	49,195
1988	47,539	1,738	49,277
1989	46,087	1,840	47,927
1990	46,033	1,840	47,873
1991	42,129	992	43,121
1992	43,201	840	44,041
1993	42,632	685	43,317

1.3 Longline Fishery

The longline fishery in Mexican waters was initiated in the early 1950s by the expansion of the Japanese longline fishery into the eastern Pacific. High catch rates of tunas, billfishes and other species of big pelagics were made in an area from about the latitude of the Revillagigedo Islands (19° N.) to the southern portion of the Gulf of California, and northwest off Baja California Sur to north of Magdalena Bay (Squire and Muhlia-Melo, 1993). The amount of longline effort within 200 miles of Mexico totalled about 4 million hooks in 1973 (Joseph, 1981). The longline effort declined rapidly off Mexico after the establishment of the 200 nautical mile Exclusive Economic Zone (EEZ) by the government of Mexico in 1976; however, longline effort increased after 1980 with the granting of longline permits to established longline joint-venture operations. Trends of effort in the eastern Pacific from 1956 to 1980 and within Mexico's EEZ limits from 1971 to 1989 are presented in Figure 1. The dominant catch of this fishery in Mexican waters was billfishes and, in lesser proportion, tunas.

1.4 Drift Gillnet Fishery

As a result of the restrictions on the use of longline gear within Mexico's EEZ a new gillnet fishery developed in 1990 with 12 boats. In 1992, 27 permits were authorized by the government of Mexico and about 24 boats were in operation in 1993. Catches of around 1,000 mt of swordfish are estimated to be landed by this fishery annually. The amounts of tunas and other species taken by this drift gillnet fishery are unknown (Squire and Muhlia-Melo, 1993).

2. REGULATIONS

In 1983 the Mexican government established a sportfishery preserve which extended from the coastline to 50 nm offshore along the Pacific coast of Mexico (Anonymous. 1983). Commercial fishing was restricted within this zone, and only Mexican flag vessels could fish

the waters outside of the restricted zone out to 200 nm. In 1987 Mexico issued new regulations regarding the inshore limits of longline operations by permit holders (Figure 2 and Anonymous, 1987a). This new limit resulted in an extension of the former prohibited fishing area to a considerable distance offshore. The new regulations established additional protected areas off the southwest coast of Baja California, the entrance of the Gulf of California, and the Tehuantepec Bight (Squire and Muhlia-Melo 1993).

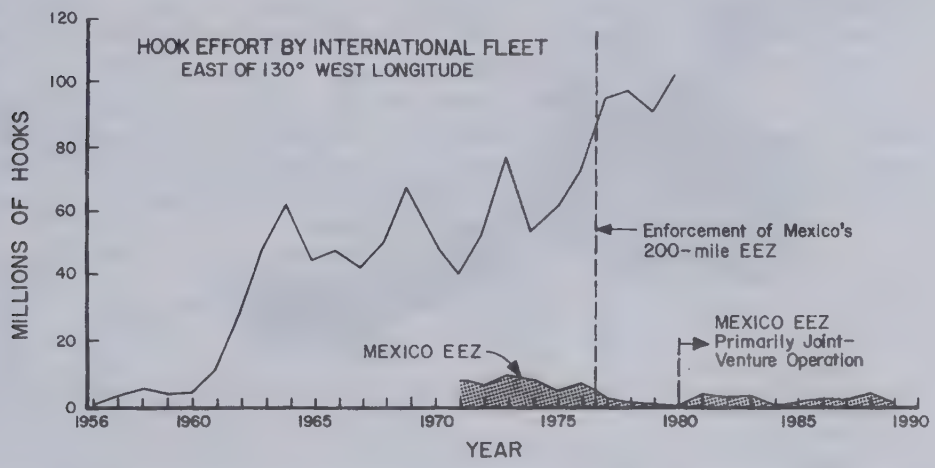

Figure 1. Longline hook effort in the eastern Pacific Ocean (east of 130W), 1956-80, and within Mexico's EEZ, 1971-89 (taken from Squire and Muhlia-Melo, 1993).

3. INTERACTIONS

3.1 Overlapping Areas of Longline and Purse Seine Fisheries

Geographical distribution of catch of tunas by the longline fishery showed high catches in areas around the west coast of Baja California peninsula and the southern portion of the Gulf of California; low catches were encountered in central areas of Mexico (see Miyabe and Bayliff, 1987 for the period 1971-1980; Nakano and Bayliff, 1992 for 1981-1987; and Maciás-Zamora et al., 1994 for 1980-1990). These areas are also covered by the purse-seine fishery in the eastern Pacific (IATTC, 1987, 1988). A schematic representation of the overlapping areas is shown in Figure 3.

A potential for interaction between longline and purse-seine tuna fisheries exists in Mexican waters. This subject for the eastern Pacific has been discussed by several authors, the more recent works have been presented by Punsly and Nakano (1992) and Nakano and Bayliff (1992). Tuna catches of the longline fishery from 1980 to 1990 ranged between 0 to 18% of the total catch (Anonymous 1987b); geographical distribution corresponds to the areas shown in Figure 3.

Longline fishing in Mexico's EEZ has not been authorized since 1990; however, there is a possibility that longlining may be reactivated in the future.

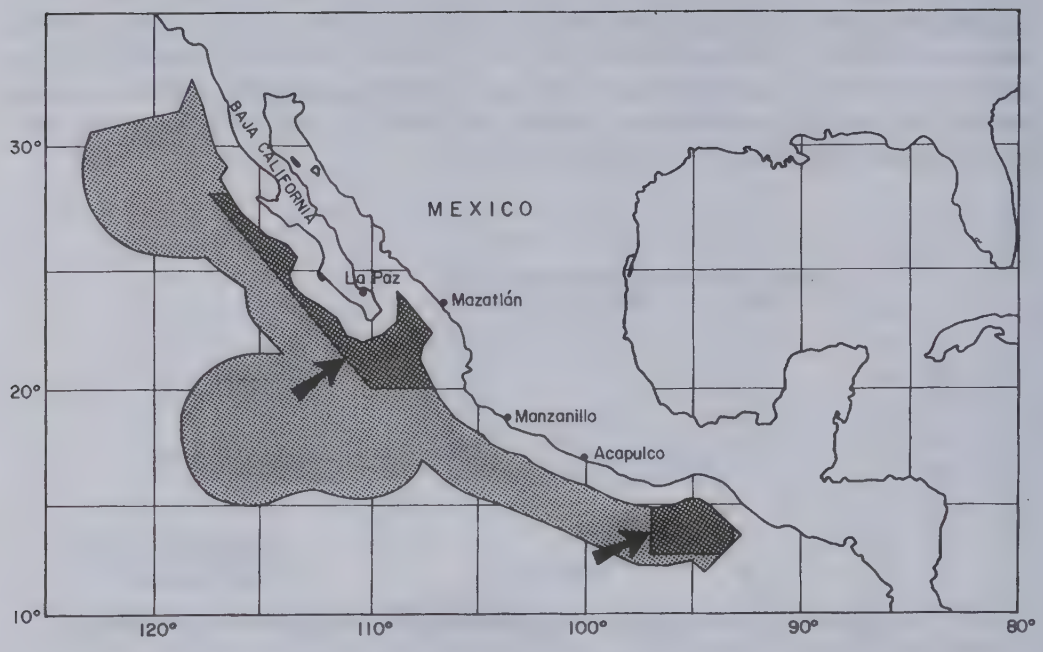

Figure 2. Areas within Mexico's EEZ restricted from directed longlining for billfishes, as of August 1987 (Anon., 1987).

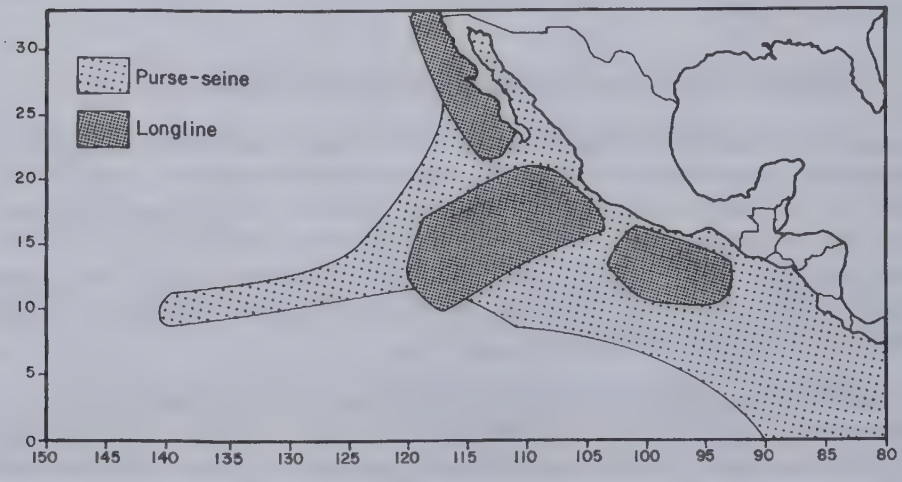

Figure 3. Schematic representation of the overlapping areas of longline and purse seine fisheries of Mexico.

3.2 Longline and Sportfishing Interactions

The 1987 regulation affected the operation of the longline fishery, but did not affect the operation of purse-seine and baitboat fishing because the regulation does not apply to tunas.

Prior to the establishment of Mexico's EEZ regulation in 1976, fishing effort by the Japanese longline fleet in the eastern Pacific (east of 130° W.) increased to about 85 million hooks (Figure 1). From 1976 to 1988 the joint-venture longline fleet applied an effort within Mexico's EEZ of about 1.9 million hooks (Figure 1). These two periods were compared in relation to the CPUE of sailfish of the sportfishing tournaments in Manzanillo (Maciás-Zamora et al., 1994). A negative trend was noted from 1956 to 1976 followed by a period of relatively stable CPUE (Figure 4). Similar patterns are observed for the striped marlin caught in the sportfishing tournaments held in Baja California Sur (Figure 5). However, these tendencies are not observed for striped marlin taken in areas of Mazatlán and Acapulco. In this case there is no evidence of the increase trends during the second period (Figure 6).

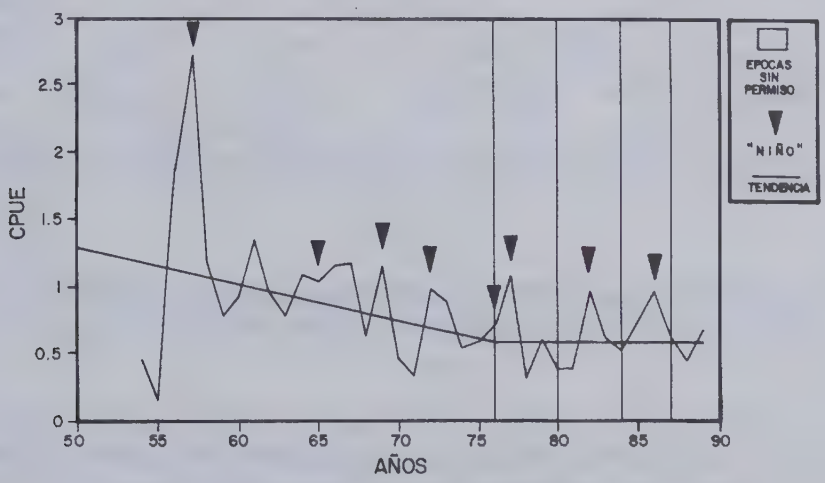

Figure 4. CPUE trend in sportfishing competitions. Arrows indicate the occurrence of the El Niño phenomenon (taken from Maciás-Zamora et al., 1984).

The interaction between the commercial longline fishery and the recreational fishery, as determined from the Angler Survey (organized by the Southwest Fisheries Science Center of NMFS in La Jolla) can be seen by examining the striped marlin catches (Squire, 1991). Longline catch rates for striped marlin off Baja California declined from about 18 fish/1,000 hooks fished to about 9 fish/1,000 fished during the period 1963-1976. Angler catch rates, determined by The Annual Billfish Angler Survey showed a decline from about 0.6 fish/day to 0.3 fish/day during the same period. Catch rates increased from 0.36 to about 0.57 fish/angler day during 1977-1980 when longline was prohibited off Mexico (Squire, 1991). During the 1982-1984 period another decline became evident; the decline seemed to coincide with the restarting of the joint-venture longline fishery. From 1985 to 1992 the catch rates of the sportfishery increased up to about 0.6 fish/angler day (Holts, 1994). The CPUE of striped

marlin taken in the sportfishing tournaments in Baja California showed a similar pattern of that of sailfish in central Mexico (Squire and Muhlia-Melo, 1993).

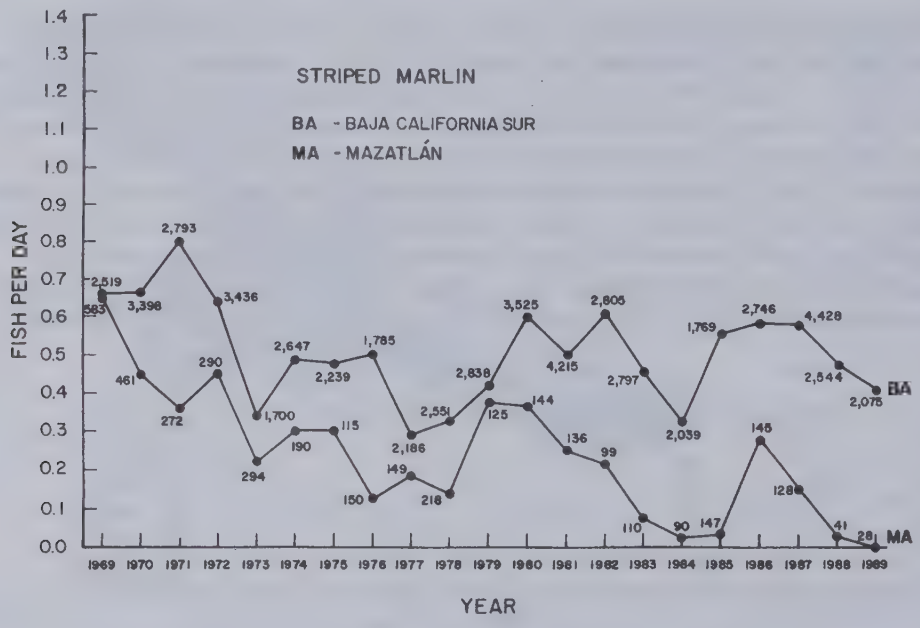

Figure 5. Angler CPUE for striped marlin off Baja California Sur and Mazatlán, Mexico (number of fish/angler-day), 1969-89 (Squire and Muhlia-Melo, 1993).

From these results we can conclude that increasing tuna/billfish longline effort in areas by recreational fisheries could have a substantial negative impact on the recreational catch, especially the billfishes. Similar situations have been observed in other parts of the world such as the Gulf of Mexico for white marlin in the Atlantic Ocean (Squire, 1991).

It is important to point out that records of the tunas captured by recreational anglers are not obtained on a consistent basis; tuna data are only collected for specific projects. There is a need to establish a data bank, where data collected from all fisheries can be maintained.

According to the distribution of the fisheries in Mexico's EEZ (Figure 3), the sportfishing areas are closest to the longline fishery along the west coast of Baja California peninsula and central-south Mexico. At present it is not possible to find any evidence of tuna interactions between the longline and the recreational fishery in Mexican waters. Tuna/billfish longline fishing permits to operate in Mexico's EEZ have not been issued since 1990.

3.3 Baitboat and Sportfishing

During the period of 1989-1993 the baitboat tuna fleet operating in Mexican waters showed a declining trend in carrying capacity; the decline was from 1,840 mt in 1989 to 685

mt in 1993 (Table 1). There is no evidence of interaction between the baitboat and sportfishing in Mexico despite the overlapping areas of operation of the two fisheries along the west coast of Baja California peninsula and at the southern portion of the Gulf of California. It is generally accepted that the baitboat fishery is capable of targeting tunas, thus, the bycatch of this fishery is very restricted. It should be noted that purse-seining with small tuna boats may be overlapping in operational area with rod-and-reel and baitboat fishing in the same coastal waters of the region.

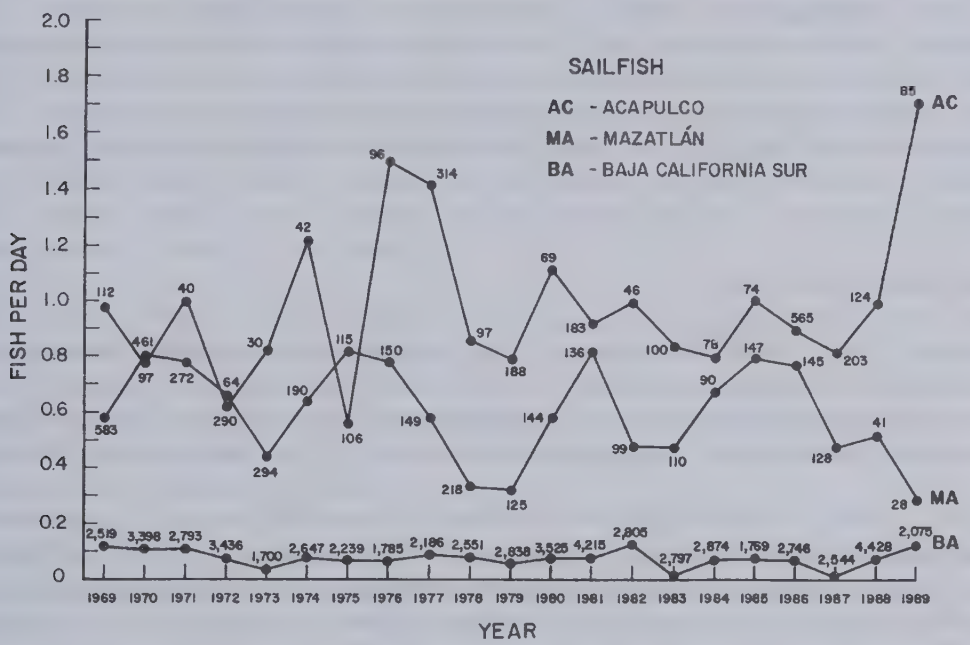

Figure 6. Angler CPUE for Pacific sailfish off Baja California Sur, Mazatlán and Acapulco, Mexico (number of fish/angler-day), 1969-89 (taken from Holts, 1994).

4. FUTURE RESEARCH

4.1 Interactions

In order to understand the existence of any interaction between these fisheries, it is necessary to establish a standardized data bank system. Sportfisheries within Mexico are very complex and extend along a considerable part of Mexico's coastline. There are about 16,000 sportfishing boats and the number of sportfishing ports is increasing steadily. Interactions may occur in different fishing areas and between different gear types. What can be concluded from this preliminary work is that there are two major areas of research to analyse fisheries interactions. One area of research is the area of high concentration of tunas and billfishes located south of the Gulf of California and northward along the west coast of the Baja California peninsula. In this area the purse-seine, baitboat, gillnet and sportfishing fisheries overlap. This area is restricted to the longline fishing. The second major area is from the

north-central Mexico, Mazatlán down to the Gulf of Tehuantepec. This is an important sportfishery area for sailfish.

4.2 Ecological Studies

There are a number of seamounts around the southern portion of the Gulf of California. It has been observed that in these locations big pelagic fishes like tunas, billfishes and sharks are known to aggregate. Studies related to the behaviour of the sharks in these locations have been carried out by Klimbley (1982, 1987); Klimbley and Nelson (1984); Klimbley and Butler (1988); and Klimbley et al., (1988). A research group from the CIBNOR initiated preliminary experiments on the ecological structure of the pelagic communities in 1992. This project involves studies of environmental factors affecting the structure of these communities, specific studies of reproduction, behaviour and food chain. Since seamounts are also important for sportfishing and commercial fishing, the results of these studies may help to understand the availability of the resources and the efficiency of fishing gears applied to fishes.

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TUNA FISHERIES INTERACTIONS IN MALAYSIA

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ABSTRACT

Neritic small tuna species including longtail tuna (*Thunnus tonggol*), kawakawa (*Euthynnus affinis*), and frigate tuna (*Auxis thazard*) have traditionally been caught in Malaysia at subsistence levels by fishermen using a variety of fishing gears. However, with implementation of the Exclusive Economic Zone, Malaysia has joined other nations in exploring waters beyond their immediate shores for commercially important pelagic finfish species such as yellowfin tuna and skipjack tuna. For Malaysia these new fishing grounds are mainly in the South China Sea off the east coast of Peninsular Malaysia and off the States of Sabah and Sarawak.

With the introduction of larger fishing boats and modern fishing gear, the fishery for tuna in Malaysia is expected to shift from the subsistence level to a commercial operation. Thus, management of these tuna resources need to be addressed so catches can be maintained at optimum sustained levels. Since it is acknowledged that these tuna resources are likely to be shared by the countries in the region, the management of these resources should be implemented on a regional basis. A study of tuna interactions of these fisheries within Malaysia and within the region should provide the basis for formulation of management measures that will ensure the proper development and exploitation of these tuna resources.

1. INTRODUCTION

Pelagic fisheries have contributed significantly to the diversified fisheries of Malaysia. Prior to the introduction of the trawl, the purse seine was the major gear exploiting the fishery resources in Malaysia. The purse seine, together with other smaller seines and the drift gillnet have been the principal gears which have contributed the bulk of the commercial marine fish landings in Malaysia up to the present time. The species that form the bulk of the commercial pelagic fish catch are mainly the scombrids (*Rastrelliger kanagura*, *R. bachysoma*, *Euthynnus affinis*, *Auxis thazard*, *Thunnus tonggol*) and carangids (*Decapterus* spp., *Auxis mate*, *Selar* spp., *Megalaspis cordyla*). Other gears used by artisanal fishermen to catch pelagic species include handlines, troll lines, and barrier nets.

The major gears used to catch tuna are the purse seine in the Malacca Straits area and the troll line, purse seine, and drift gillnet in the South China Sea area (Figure 1).

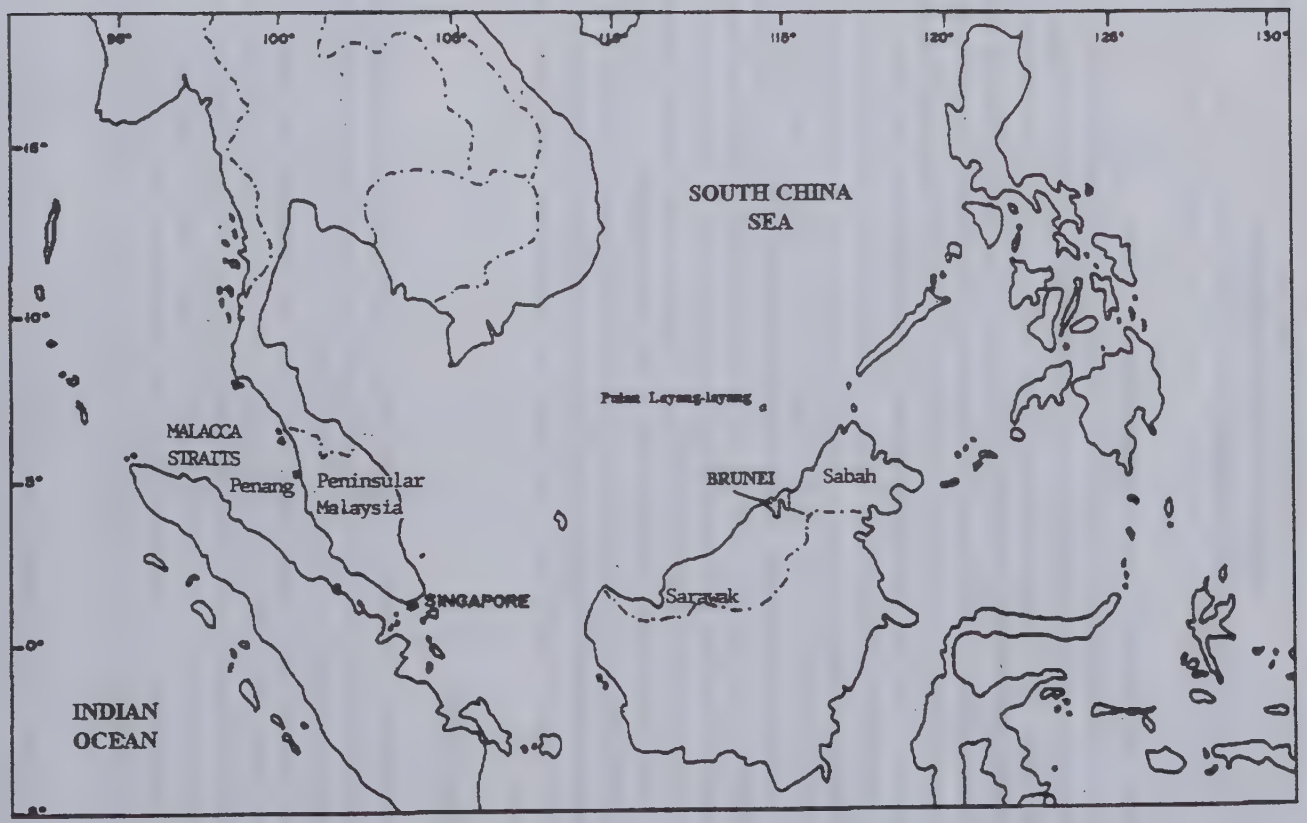

Figure 1. Map of Malaysia.

2. DEVELOPMENT OF PURSE SEINE TUNA FISHERY IN MALAYSIA

During 1987 and 1988 experimental purse seine fishing trials for tuna were conducted in Malaysia's Exclusive Economic Zone (EEZ) of Pulau Layang-Layang (Figure 1) by a research vessel (Gambang and Chong, 1988) as well as a commercial purse seiner (Johari, 1989). Fishing was conducted in conjunction with fish aggregating devices (FADs). An average catch rate of 14 mt per haul was recorded by the commercial purse seiner. In mid-1994, the vessel (K.L. PAUS) of the Malaysian Fisheries Training Institute conducted fishing trials in conjunction with FADs; the average catch was 15.5 mt per haul. It was noted that the aggregation of tuna by FADs varied with time of year and the sea surface condition (Johari, 1989, Gambang, in press). More fish seemed to aggregate under FADs between the months of March to June. Aggregations by FADs may also vary with the migration pathways of the tuna.

The experimental fishing carried out in the Pulau Layang-Layang area gave some interesting results. Fishing with vertical handlines at depths ranging from 200 m to 300 m yielded 90% yellowfin tuna (*Thunnus albacares*) and 10% skipjack tuna (*Katsuwonus pelamis*). The yellowfin ranged in size from 1 kg to 60 kg. There is a possibility that some small bigeye tuna (*Thunnus obesus*) were caught, but were misidentified as yellowfin tuna. Purse seine catches consisted of 85% skipjack tuna weighing between 1 to 4 kg per fish; the remaining 15% of the catch consisted of yellowfin tuna. Fishing with vertical longlines and purse seines were carried out in conjunction with FADs. It was also reported that more fish were caught around FADs set in deep trenches (Johari, 1989). Fishing with the longline yielded mainly bigeye tuna; individuals ranged between 20 kg and 70 kg (Gambang, in press).

Following the experimental fishing trials, commercial tuna fishing in Malaysia commenced with the purse seine and vertical handline gears as the principal fishing gears used.

3. OTHER TUNA FISHERIES IN THE REGION

Similar to Malaysia, the Philippines, Indonesia, and Thailand use purse seine, longline and vertical handlines to fish for tunas in the region; the same oceanic and neritic tuna species are also taken. In the Philippines the marked increase in growth of the tuna fishery has been attributed to the use of FADs (called payaos in the Philippines). Yellowfin tuna, skipjack, and frigate tuna (*Auxis thazard*) are the principal species caught in the Philippines. Purse seines, ring nets, and handlines catch juvenile yellowfin ranging in size from 16 cm to 55 cm. Since few yellowfin between 60 cm to 200 cm are caught by the Philippine tuna fishery, it has been suggested that juvenile yellowfin start to migrate out of Philippine waters at 30 cm size, and that most of these juvenile yellowfin are gone from the region by the time they reach 60 cm in length. Yellowfin larger than 110 cm are caught by hook-and-line fishermen in the northern Celebes Sea (Aprieto, 1989).

In Indonesia the yellowfin tuna and skipjack are the dominant species in the catch. The use of FADs (called rumpons in Indonesia) also play an important role in the development of the Indonesian tuna fishery. Presently tuna are caught by a variety of gears including purse seines, handlines, troll lines, and longlines (Anon., 1993)

The development of the Thai tuna fishery was catalysed by the development of the canned seafood industry in the early 1980s (Bhatia et al., 1989). Prior to this development, the target species of the marine fishery were the small pelagics; tunas were considered as bycatch of the pelagic fishery. With the increased demand for tuna, the purse seine fishery in Thailand began to target small tunas including the longtail (*Thunnus tonggol*), kawakawa (*Euthynnus affinis*), and frigate tuna (*Auxis thazard*). The bulk of the catch was directed to the canneries. The purse seine and gillnet fisheries have contributed very impressively to the increased tuna landings in Thailand (Anon., 1993).

4. TUNA LANDINGS IN THE REGION

The total landings of tuna in Malaysia show a steady increase from around 6,000 mt in 1970 to a high of 35,000 mt in 1992 (Figure 2). The bulk of the tuna landed came from the east coast of Peninsular Malaysia; the west coast of Peninsular Malaysia contributed only small quantities of tuna. Until 1991 the tuna catch recorded in the states of Sabah and Sarawak were very small; however, in 1991 and 1992 these states recorded the highest tuna catch for all of Malaysia. Landings for both states together totalled 13,000 mt and 19,000 mt for 1991 and 1992, respectively. The major increase in tuna landings came from the expansion of the commercial tuna fishery into the EEZ waters of Malaysia, mainly around Pulau Layang-Layang area in the South China Sea. It expected that the tuna production in Malaysia will continue to show substantial growth in the future.

Figure 3 shows the landings of tuna and tuna-like fishes (this category includes billfish and seerfish) by countries in the Southeast Asia region. The two countries with the highest recorded tuna landings are the Philippines and Indonesia, followed by Thailand and Malaysia.

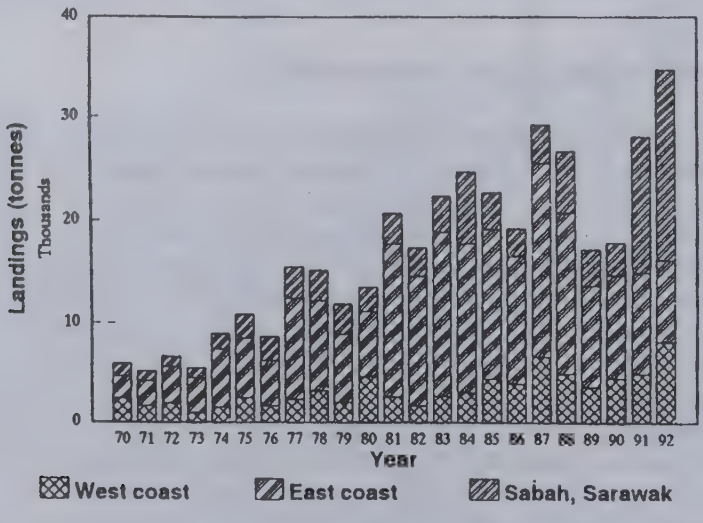

Figure 2. Tuna landings in Malaysia, 1971-92.

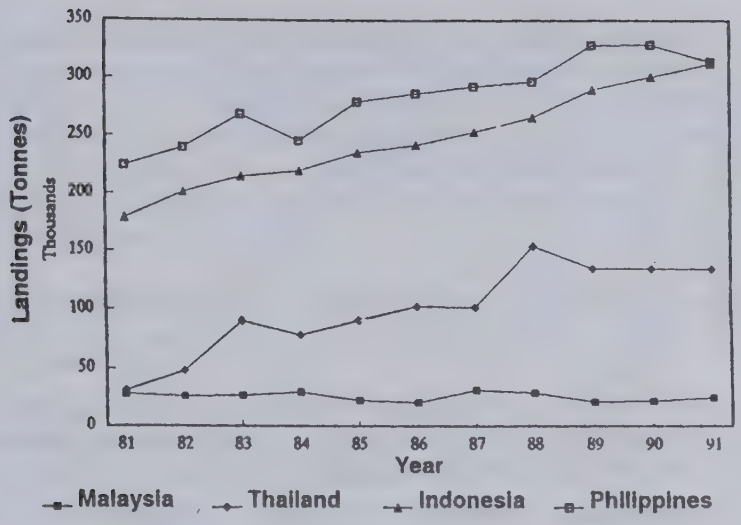

Figure 3. Tuna, billfish and seerfish caught in Area 71, by country, 1981-91.

5. INTERACTION BETWEEN THE TRADITIONAL TROLL FISHERY AND THE COMMERCIAL PURSE-SEINE FISHERY IN MALAYSIA

Traditionally the troll line operators of Kuala Terengganu on the east coast of Peninsular Malaysia targeted tuna and Spanish mackerel. Trolling is carried out on small boats using about four lines per boat. The number of hooks per line ranges from 2 to 25: the number of hooks per line is increased if fishing success is high. These boats usually perform trips of 3-4 days duration; the operation of these trollers has been described by Chee (1989). Landings by these trollers were reported to be the highest relative to other gears used to catch tuna (Figure 4).

Since late 1987, a fleet of 40 purse seiners has fished in the South China Sea mainly for tuna. With the introduction of this purse seine fleet, the small tuna resources of this area has been shared by troll vessels and purse seiners. With the introduction of the purse seine fishery a number of interaction problems arose. Initially these purse seiners intended to fish for free-schooling small tuna in the South China Sea; however, in actual fishing operations spot-lights were used by these vessels to aggregate fish. The purse seiners, thus, caught the larger free-swimming tunas and also small pelagics which aggregated in response to the spot-light (Chee, 1992). With the influx of the purse seiners, the catches of the trollers were expected to decline; this decline was observed (Figure 4). It was noted that while the purse seiners are capable of ranging over a wide fishing area, the trollers by virtue of their small size and type of gear were limited to the traditional fishing grounds in the vicinity of the oil rigs off Terengganu in the South China Sea. It appears that a direct interaction exists between the purse seine fleet and the troll fishery; it was also noted that the drift gillnet fishery may also be affected.

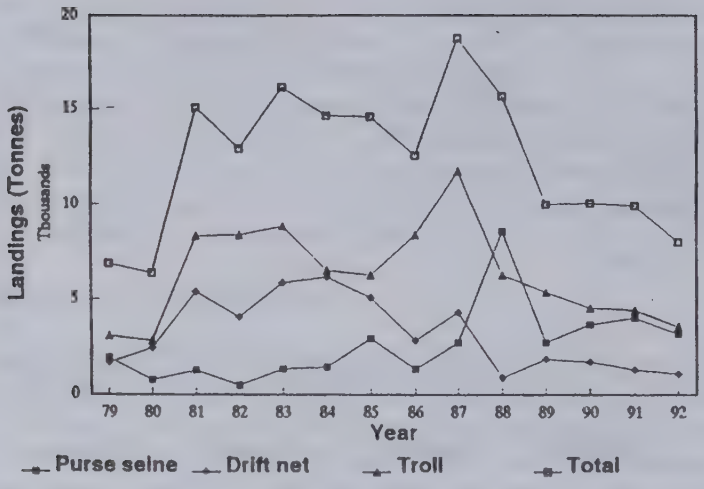

Figure 4. Tuna landings in east coast peninsular Malaysia, by gear, 1979-92.

The catch by gear of the tuna fisheries of Malaysia are shown in Figure 4. Except for 1986 and 1987, the catch of the troll fishery show a gradual decline in catch from 1983; increased landings were noted for 1986 and 1987. The drift gillnet fishery also shows a gradual decline in catch which started in 1984. Unlike the troll and drift gillnet fisheries, the purse seine fishery shows an increase in landings from 1982; the 1988 catch was unusually high.

While interaction between the purse seine fishery and the traditional troll and drift gillnet fisheries may be a factor contributing to the decline in catches of the latter two fisheries more detailed studies of the dynamics of the fisheries need to be carried out in order to verify and quantify this interaction. As noted earlier the increase in the catch of the purse seine fishery may be due to the movement to newer and more productive grounds further offshore.

6. INTERACTION IN THE HARVEST OF TUNA BY COUNTRIES IN THE REGION

As early as 1989, a decrease in size of longtail tuna was reported from the monitoring of the troll fishery at Terengganu. The average size of longtail tuna caught by trollers increased from 1983 to 1987 from 35.2 cm to 36.6 cm. In 1988 the mean size declined to 33.2 cm and still smaller size to 32.6 cm in 1989. General declines in the mean size of longtail tuna caught by the Thai purse seine and gillnet fisheries were also observed in 1989 relative to earlier years (Yesaki, 1994). The mean size of kawakawa also decreased in 1989 (Yesaki, 1994). However, the mean size of frigate tuna showed an increase in 1987 and a decrease in 1989 (Yesaki, 1994).

The decreases in mean size could result from increased exploitation rates of these tuna species by Malaysian fisheries as well as other countries fishing in the region. Since this inference was made on the basis of fishery-related information, more evidence should be

gathered from further monitoring of these stock(s) in the region. More biological information on the migration and distribution of the tuna stock(s) also need to be collected. Some studies of this nature have been initiated in Malaysia; these studies include tagging of small tuna to study their migration and distribution in the region (Raja Bidin, 1990). In an effort to identify unit stock, a study of the distribution of tuna larvae was initiated (Liew, personal communication); similarly, the use of parasites as biological indicators of stocks was also attempted (Faizah, et al., 1988).

7. A REGIONAL APPROACH IN STUDYING INTERACTIONS OF TUNA FISHERIES

From the above discussion, it appears likely that interactions exist among the tuna fisheries of neighbouring countries in southeast Asia. The harvesting of tuna at a particular time, age, and size by one country will definitely affect the catch of another country if common resources are involved. Thus, the size segregation of tuna species by gear and fishing grounds needs to be studied.

Conspicuous shortcomings in the available documentation of the biology of tuna species of the region is the lack of information on the distribution and migration of the several species involved and the virtual lack of stock structure information. Solution to these basic problems cannot be achieved without the concerted effort of all parties involved with the fisheries. While biological information is being collected independently by countries fishing in the region, the information is not readily available; in many instances the information is inadequate for proper assessment. It appears a coordinated regional approach is necessary to gather the appropriate data and to carry out the analyses and interpretation of the data that could lead to effective management. Therefore, effort should be undertaken to establish a regional approach to research and management of the resources in the region. Recognizing this need, a few regional projects directed toward management of shared stocks have been proposed for implementation by the Southeast Asian Fisheries Development Center (SEAFDEC), in Kuala Terengganu, Malaysia (Raja Bidin, 1994). These projects include the collection and documentation of catch and effort data and biological data, the latter includes carrying out spawning ground surveys and tuna tagging programmes.

8. CONCLUSION

Interaction in the tuna fisheries of Malaysia relate mainly to resource allocation by fishing gear used within the country. The problem of resource allocation also arises out of the harvest of the same tuna stock(s) by countries fishing in the same region. Using the most efficient fishing gear, each country harvests the tuna at a particular size and at a particular point in the migration route. Thus, the harvest of tuna by one country impacts the present and future catches of the same stock(s) of tuna by countries which harvest these resources later on in the migratory route of the tuna.

Recognising this, there is an urgent need to study interactions among fisheries nationally and regionally. Without a coordinated and directed approach to gather, document, analyse, and interpret the relevant data, the tuna fishery resources in the

southeast Asia region cannot be assessed and managed effectively to ensure sustained harvests.

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MONITORING LANDINGS OF TAIWANESE TUNA LONGLINERS AT PENANG HARBOUR

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ABSTRACT

Foreign fishing boats, particularly Taiwanese tuna longliners, are attracted to Penang because of her strategic location in the Straits of Malacca and the support of good port and communication facilities. Monitoring of the total landings of tuna by Taiwanese tuna longliners began in 1990. From mid-1992 until the end of 1993, the monitoring of tuna landed and transshipped through Penang was done more systematically with the financial support of the Indo-Pacific Tuna Development and Management Programme (IPTP). From this monitoring programme information on total catch, species composition, and size information of the major tuna species, i.e., yellowfin tuna was compiled. The seasonality of fishing activities, fishing grounds and fishing vessel information were documented. The increase in longlining for yellowfin in the eastern Indian Ocean may cause possible interactions among tuna fisheries in other parts of the Indian Ocean. The information collected from this monitoring programme is important since without this documentation, a good part of the information relating to the exploitation of the tuna resources in the Indian Ocean will not be known.

1. INTRODUCTION

During the 1960s, Penang served as a landing and transshipment port for foreign tuna fishing vessels. This activity ceased in the 1970s but had resumed since the mid-80s. The number of Taiwanese tuna fishing vessels discharging their catch at Penang Harbour has increased since the mid-80s due to Penang's strategic location, good support facilities, good international air and sea linkages, and the presence of similar cultures (Mohamad, 1993).

The Taiwanese started tuna longline fishing in the Indian Ocean in 1963. Initially their main target was albacore (*Thunnus alalunga*), but two years later switched to yellowfin tuna (*Thunnus albacares*) and bigeye tuna (*Thunnus obesus*) (Hsu and Liu, 1991).

The tuna longliners that land at Penang Harbour are generally small vessels averaging 50 GRT and are powered by engines of about 400 hp. These vessels operate for a duration of up to one month at sea. The fishing grounds in the Indian Ocean lie mainly between 0-10°N latitudes and to 80-95°E longitudes. Each vessel has 7-10 crew members. Fishing is

usually carried out at depths between 45-70 m. A description of the fishing vessels, their gear and mode of operation was documented earlier (Khoo and Chee, 1994). The bulk of the tuna is exported to Japan in the chilled form for the sashimi market. Second-grade tuna are sold in the frozen form both to local and foreign canneries.

2. TOTAL LANDINGS

The total recorded landings of tuna in Penang from 1990 to September 1994 are shown in Figure 1. For the four year period, a clear seasonality in landings was observed. Landings of tuna peak in December/January annually while the lowest recorded landings were in the middle of the year. Total landings ranged from 136 tonnes per month to 2,040 tonnes per month over the period covered from 1990 to September 1994. It is of interest to note that the highest landings corresponded with the highest demand of the Japanese sashimi market which occurs during the New Year period.

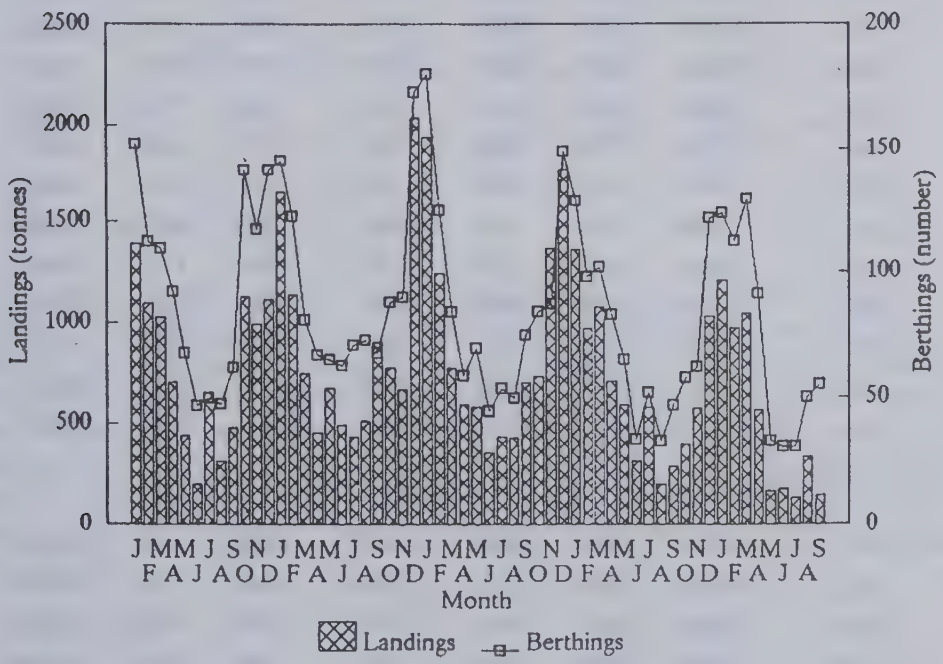

Figure 1. Berthings and landings, 1990-94 (data from Penang Port Commission).

3. TOTAL NUMBER OF BERTHINGS

Figure 1 also shows the number of berthings recorded by the Penang Port Commission. The highest number of berthings were recorded also during the months of December of one year and January of the following year. There is a close correlation between the number of berthings and the quantity of tuna landed.

4. SPECIES COMPOSITION

Table 1 shows the species composition of sampled landings by month for 1992 and 1993. It is clear that yellowfin tuna (Figure 2) always made up the highest proportion of the landings; bigeye were landed in smaller amounts. Marlins (*Makaira indica, M. mazara* and *Tetrapturus audax*), swordfish (*Xiphias gladius*), sailfish (*Istiophorus platypterus*), skipjack tuna (*Katsuwonus pelamis*), wahoo (*Acanthocybium solandri*), barracudas (*Sphyraena*), and a few species of sharks were also landed.

Table 1. Composition of Taiwanese longline landings (kg) at Penang Harbour, 1992-93.

Year	Month	Yellowfin	Bigeye	Marlins	Swordfish	Sharks	Others	Total
1992	Jan.	424852	32176	19035	7992	7318	5996	497369
	Feb.	228311	36614	10985	6548	3434	2536	288428
	March	126324	20417	6256	1922	1967	1566	158452
	April	37029	6403	2759	1099	492	1352	49134
	May	69163	7637	4938	4862	1387	3464	91451
	June	20384	2133	1956	246	542	137	25398
	July	34389	7586	7787	4533	7310	5989	67594
	Aug.	13805	1055	993	1589	6345	1172	24959
	Sept.	58797	17452	8980	8817	3637	8660	106343
	Oct.	60357	7622	7484	4790	4754	5610	90617
	Nov.	122033	20907	9555	2978	3880	3825	163178
	Dec.	371523	80470	27579	6235	2945	4329	493081
1993	Jan.	317381	52654	19200	5808	4823	4194	404060
	Feb.	276376	61624	10101	3296	2864	7168	361429
	March	206259	89623	6957	3352	1853	5003	313047
	April	140353	38189	1449	1417	596	5582	187586
	May	158014	24116	18613	1261	632	4209	206845
	June	66223	10259	7718	2043	1886	5500	93629
	July	35378	12827	5337	3004	581	3548	60675
	Aug.	47141	15980	6944	6838	1408	7205	85516
	Sept.	124643	25293	8711	7702	3509	8271	178129
	Oct.	46806	8746	8753	2680	1372	3503	71860
	Nov.	68578	32719	19247	10411	6093	14265	151313
	Dec.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

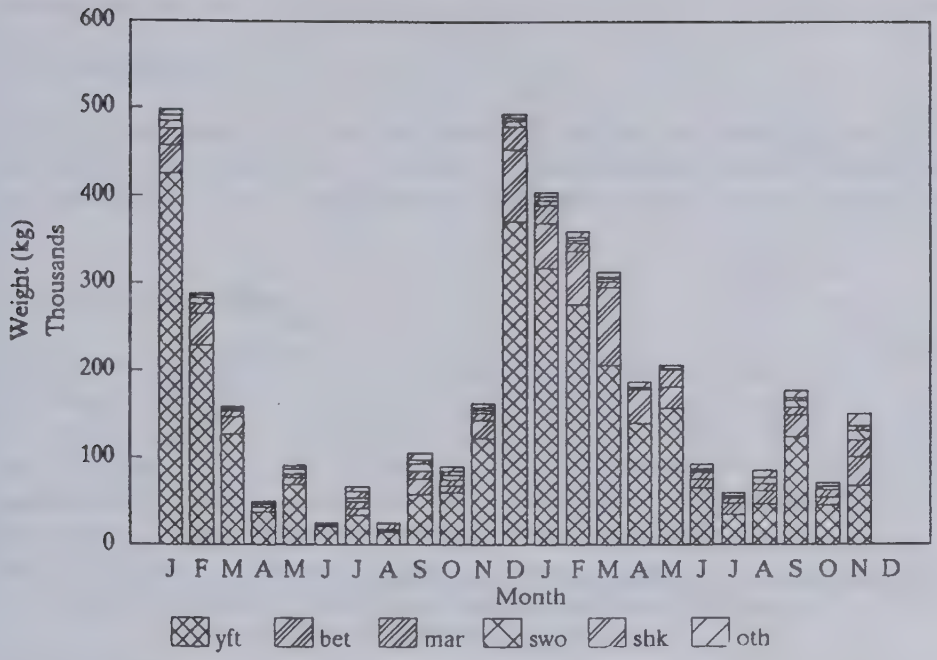

Figure 2. Species composition of Taiwanese longline landings at Penang Harbour, 1992-93.

5. SIZE COMPOSITION

The average gilled-and-gutted weight of yellowfin and bigeye tuna sampled by month in 1992 and 1993 is shown in Figure 3. For both yellowfin and bigeye tuna, the average gilled-and-gutted weights, were low during the third quarter of the year. This shows that more large fish were caught during the time of peak fishing activity. However from Figure 4, it can be seen that the weight of fish landed per berthing (or per fishing trip), appears to be rather consistent, i.e., approximately 10 tonnes per berthing. This quantity of fish is possibly limited by the size of the fish hold of the vessel as well as by the saturation time of handling of the fish on board to maintain the quality desired for export to the Japanese sashimi market.

6. HANDLING

6.1 Tuna for Sashimi

On board the fishing vessel, tuna directed to the sashimi market are killed, dressed and chilled immediately after capture. The fish are also to be handled gently, yet quickly, to prevent bruises and the condition called "yake niku" or burnt flesh. Fish in this condition cannot be sold for sashimi because of their unpleasant appearance, acidic flavour and metallic after-taste (Putro, 1990). Fish that are not dressed on board are gilled-and-gutted at the landing site. Sashimi-grade tuna are chilled with crushed ice. Fish for export are packed in cartons with dry ice while second-grade tuna are usually frozen and sold to local canneries or exported.

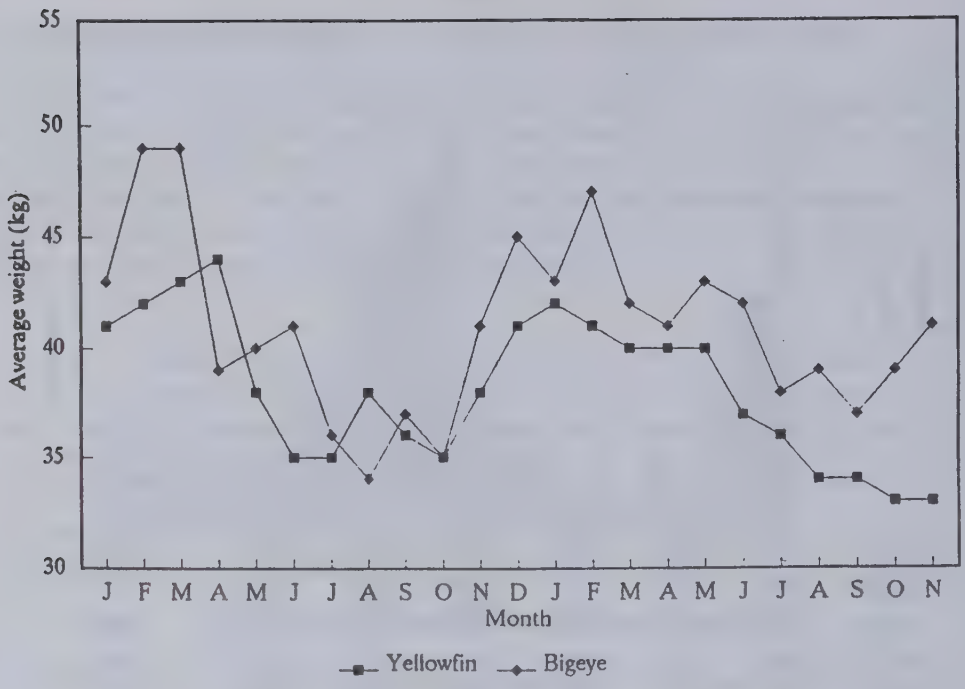

Figure 3. Average gilled-and-gutted weight of yellowfin and bigeye tuna.

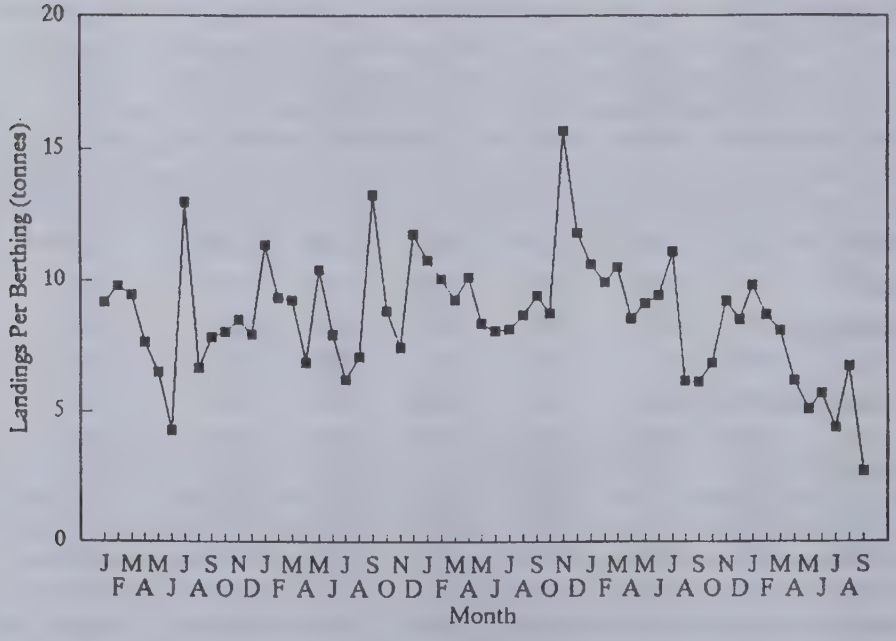

Figure 4. Landings per berthing recorded at Penang Harbour, 1990-94 (data from Penang Port Commission).

6.2 Other Bycatch

Almost all the bycatch are killed and eviscerated and the heads and fins are cut off before being stored in deep freeze. However some prime quality marlins are also chilled and sold for sashimi as well. Swordfish are usually exported to European markets for fish steak.

6.3 Possible Interactions

The increase in longlining for yellowfin in the eastern Indian Ocean may affect the present fishing activities in the western part of the Indian Ocean. In the western Indian Ocean, fishing primarily by Spanish and French purse seiners catch yellowfin in addition to skipjack (Lablache, 1991). Thus interaction may arise from the fishing of the same species but at different life cycle stages since purse seiners generally catch smaller size fish from surface schools. Fishing in parts of Indonesia, which also uses the longline, may be affected, e.g., in areas to the west of Sumatra, where a similar fishery targeting for sashimi-grade tuna has recently developed (Naamin and Bahar, 1994).

7. DISCUSSION

Penang has benefitted from the transshipment activities of the Taiwanese tuna longliners. Besides accruing revenue directly from the fishing activities, several activities associated with the transshipment business have been initiated, e.g., development of milkfish farms to supply live bait for tuna longliners. These activities will increase and will continue to support the fishing operations for oceanic tuna in the Indian Ocean if the resources are sustained. Since yellowfin are reported to move extensively, it would be desirable to continue the collection of these data to examine possible interaction issues related to the yellowfin resource in the eastern Indian Ocean to support the proper management of these oceanic tuna resources.

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INTERACTION OF THAI TUNA FISHERIES: PROBLEMS, RESEARCH AND DEVELOPMENT

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ABSTRACT

This report presents an overview of tuna fisheries in the Gulf of Thailand. The data on small tunas, mainly longtail tuna (*Thunnus tonggol*), kawakawa (*Euthynnus affinis*) and frigate tuna (*Auxis thazard*), caught by drift gillnet and purse seine are examined for possible interactions between these two fishing methods. The report also provides information about research on small tunas, fishery development, and prospects for further development. Additionally, problems are identified and recommendations made.

1. INTRODUCTION

Until 1979 tunas were a relatively minor part of the pelagic fisheries of Thailand. The catch statistics of Thailand classified tunas collectively as "bonito" without a breakdown into species. Tunas are caught by purse seines and drift gillnets year-round. The development of a fish canning industry in Thailand during the late 1970s increased the demand for mackerel, scad, sardine, and especially tuna. By 1982 tunas had become the main target species of Thai fishermen (Figure 1) because of the high price offered by the tuna canneries. This demand encouraged Thai fishermen to seek tunas as their target species and to increase the catch through improvement of fishing gears, as well as expanding the fishing grounds farther offshore. The rapid development of tuna fisheries has resulted in a spectacular increase of tuna production, from 3,300 mt in 1971 to 156,208 mt in 1990. Presently, Thailand is the main supplier of canned tuna to foreign markets throughout the world.

2. RESOURCES

2.1 Exploited Species

There are three main species of small tunas caught commercially in Thai waters--longtail tuna (*Thunnus tonggol*), kawakawa (*Euthynnus affinis*) and frigate tuna (*Auxis thazard*). The predominant species, longtail tuna, is preferred by canners and commands the highest price among the three species; the higher price is due to the preferred lighter colour of longtail tuna as a canned product. Besides these three species, skipjack tuna (*Katsuwonus pelamis*), yellowfin tuna (*Thunnus albacares*), bigeye tuna (*Thunnus obesus*), dogtooth tuna (*Gymnosarda unicolor*) and oriental bonito (*Sarda orientalis*) are also caught occasionally in small quantities in neritic waters.

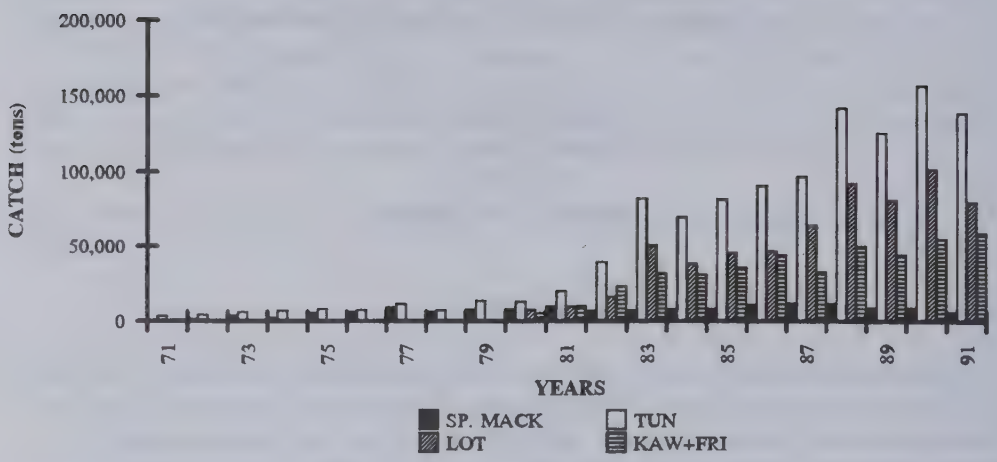

Figure 1. Catch of small tunas and Spanish mackerel in the Gulf of Thailand, 1971-91. TUN=combined tuna species, LOT=longtail tuna, KAW=kawakawa, FRI=frigate tuna, SP. MACK=Spanish mackerel.

2.2 Distribution

Small tunas are migratory and widely distributed along the continental shelf at depths ranging from 20 to 75 m. They occur in large schools in offshore waters and are seasonal visitors to coastal areas. The small tunas concentrate in the inner neritic waters.

Longtail tuna are found farther offshore than kawakawa and frigate tuna. Longtail tuna moves into the Gulf of Thailand and enter the fishery as recruits at a size of 20 cm during October to February; fish larger than 40 cm generally remain in the outer neritic waters. During the northeast monsoon, longtail tuna are abundant in the eastern coast of the Gulf until January. Later they move to the western coast to feed, and by June-July longtail tunas disappear from the west coast, possibly migrating to the South China Sea area to spawn.

Kawakawa are also distributed along the continental shelf throughout the year. Small kawakawa (from 18 cm in length) are captured in the coastal areas in the inner and outer neritic waters and over the continental slope during October-January. Available evidence suggests that this species is not as segregated by size as is the case with longtail tuna.

Frigate tunas are principally distributed in the inner neritic waters. Frigate tuna move to offshore waters during February-May when they reach lengths of about 30 cm.

3. FISHERIES

The purse seine and Spanish mackerel drift gillnet fisheries contribute more than 95% of the total tuna catch (Table 1). The Thai purse seine evolved from the Chinese purse seine and became widely used in Thailand, particularly after 1957. The Thai purse seine

has developed as a unique style of seining appropriate to conditions in Thai waters. This gear was developed initially to catch small pelagic fish other than tunas. The targeting of small tunas by the Thai purse seine fishery started in 1982 with the expansion of the tuna canning industry. Thai purse seining is labour-intensive with 30-40 crew members working on vessels ranging in size from 25-30 m. The length of nets range from 800-1,250 m, while net depths range from 70-120 m, and mesh sizes range from 2.5-9.7 cm. Modern purse seiners are equipped with radar, depth sounder, sonar transceiver and satellite navigational instruments. Recently, some purse seiners have been equipped with power blocks to reduce labour and to permit use of longer and deeper nets with large meshes in the wings and bunt.

Spanish mackerel drift gillnets have played an important role in these tuna fisheries, especially in the early period of development. At present, the drift gillnets are less important for capturing tunas when compared to purse seines. The fishing boats used by this type of gear are mostly small to medium-sized vessels ranging from 14-18 m in length. The length of the gillnet varies from 1-12 km, and the depth is usually 7.5 m. The mesh size is rather large, ranging from 9-11 cm stretched. The gillnet are usually operated around islands or near seamounts. The gillnet fishery for small tunas has not changed much; exceptions are an increase in net length resulting from the adoption of mechanised haulers, and a movement farther.

Table 1. Species compositions of tunas caught from the Gulf of Thailand and the South China Sea, 1979-91. LOT=longtail tuna, KAW=Kawakawa, FRI=frigate tuna. Source: Marine fisheries statistics (Department of Fisheries, 1979-91).

Unit: %

	Purse Seine			Drift Gillnet		
Year	LOT	KAW	FRI	LOT	KAW	FRI
1979	77.0	23.0	-	54.0	46.0	-
1980	62.7	37.3	-	54.3	45.7	-
1981	47.8	52.2	-	50.3	49.7	-
1982	24.7	75.3	-	52.1	47.9	-
1983	64.5	25.7	9.8	43.6	56.4	-
1984	62.6	37.4	-	38.1	61.9	-
1985	59.1	40.9	-	39.2	60.8	-
1986	54.9	45.1	-	42.2	57.8	-
1987	57.1	21.4	21.5	26.9	43.1	30.0
1988	77.5	12.5	10.0	78.1	12.6	9.3
1989	68.0	18.5	13.5	50.1	39.0	10.9
1990	66.0	21.7	12.3	47.9	42.0	10.1
1991	58.5	25.9	15.6	39.8	39.0	21.2
Average	60.0	33.6	6.4	47.4	46.3	6.3

3.1 Fishing Gear

There are two types of purse seine registered in the Gulf of Thailand--Thai purse seine and luring purse seine. Luring purse seines are modified from Thai purse seines and involve the use of coconut leaves as fish attraction devices. In recent years, the luring

purse seines began using modern equipment such as generators, colour echo-sounders, sonar, radar and satellite navigational devices to increase fishing efficiency.

The number of registered Spanish mackerel drift gillnets (Figure 2) showed an increasing trend from 1971 to 1988, with slight declines noted in 1978, 1982 and 1989. The number of Thai purse seines showed a decreasing trend from 1973 to 1983 and, subsequently, they increased dramatically and reached a maximum in 1991. The number of luring purse seines showed a trend that was opposite to the Thai purse seines. However, it is difficult to accurately separate the Thai and luring purse seines because identification of those two types of purse seines is not clear, and the final gear designation is left to the fishermen's discretion during registration. With regard to the number of combined Thai and luring purse seines, the total shows a steady increasing trend from 1971 to 1991 with a marked drop in 1989 (Figure 2).

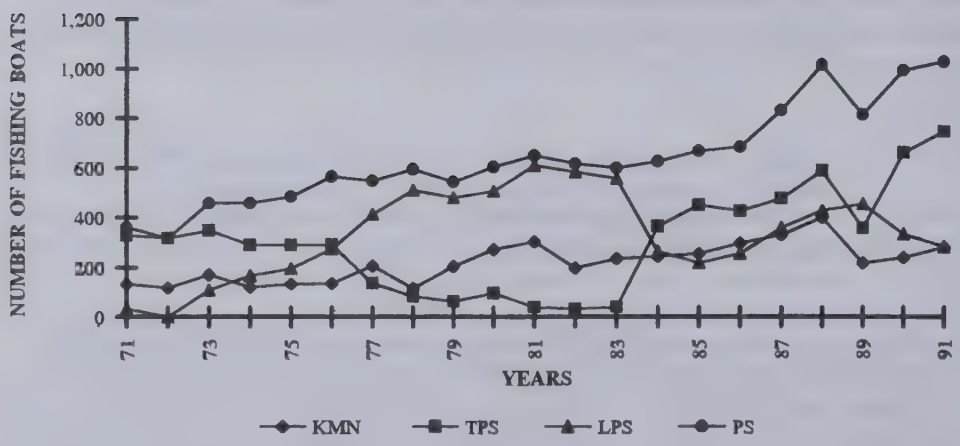

Figure 2. Number of fishing boats by type of fishing gear registered in the Gulf of Thailand, 1971-91. KMN=drift gillnet, TPS=Thai purse seine, LPS=luring purse seine, PS=total purse seine.

3.2 Species Composition

The longtail tuna is the dominant tuna species landed by the purse seine and drift gillnet fisheries. During the period 1979 to 1991 longtail tuna made up an average of 60% and 47.4% for the annual catch of the two gears, respectively; the rest of the catch consisted mainly of kawakawa and frigate tunas (Table 1). Skipjack and yellowfin tunas are found farther south in the Gulf of Thailand and in the South China Sea. Presently, fisheries targeting skipjack and yellowfin do not exist.

The percentage of small tunas caught by purse seine and Spanish mackerel drift gillnet are shown in Figure 3. It appears the small tunas were an important part of the Spanish

mackerel drift gillnet fishery, even prior to the dramatic increase in demand for tuna in the early 1980s. Small tunas comprised 30-50% from 1972-80, and 60-70% from 1982-91. It may be possible that the increase in the catch of small tunas since 1982 is due to movement offshore by the drift gillnet fishery in response to higher prices offered for tunas. Small tunas caught by purse seines showed a gradual increasing trend throughout the period from 1976-91, and the increase in the tuna portion of the catch has been steady since 1981. In 1981 small tunas comprised only 3% of the total catch, and by 1990 had reached a high of 31%. The non-tuna component of the purse seine catch was comprised mostly of small pelagic fish, i.e., mackerel, sardine, round scad and other carangids.

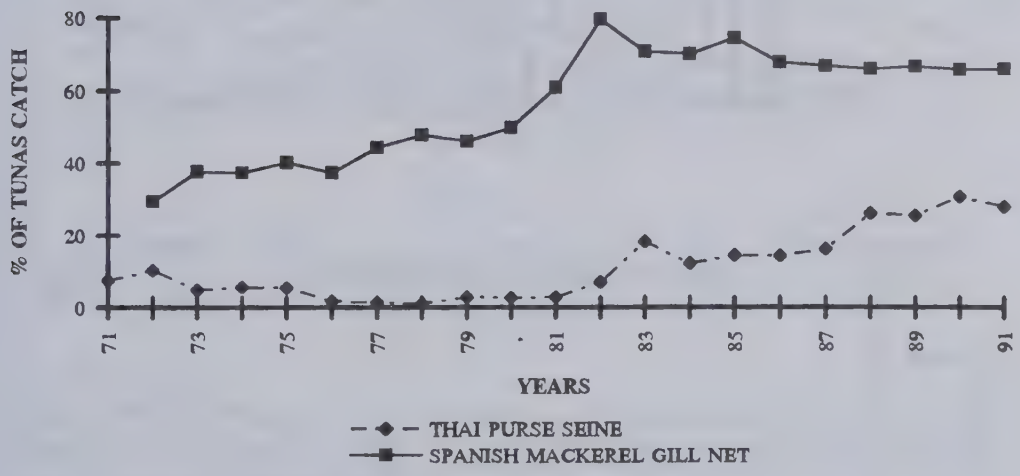

Figure 3. Small tunas caught by Spanish mackerel drift gillnet and Thai purse seine in the Gulf of Thailand, 1971-91.

3.3 Production

The catch of tunas by purse seines showed an increasing trend throughout the period. In 1972, tuna landings by purse seine was only 2,600 mt; annual landings increased gradually to a high of 8,700 mt in 1981. Subsequently, there was a dramatic increase in tuna landings that reached a high of 145,000 mt in 1990. In 1991, the catch declined slightly, accounting for 129,500 mt (Figure 4).

The annual catch of the Spanish mackerel drift gillnet fishery showed an increasing trend from 1971-82. From 1982 to 1988 the catch stabilised at about 11,000-19,000 mt; thereafter, the catch declined and accounted for less than 10,000 mt in 1991 (Figure 4). Since 1982, the catch of small tunas by the Spanish mackerel drift gillnet fishery and the purse seine fishery appear to be headed in opposite directions. The tuna catches of drift gillnets and purse seines were of equal magnitude up to 1982; thereafter, production by purse seines exceeded that of gillnets. The increase was due to improvements in fishing

efficiency, expansion of fishing grounds into deeper waters, and an increase in effort by purse seiners. It may be possible that interaction between these two types of fishing gears exists.

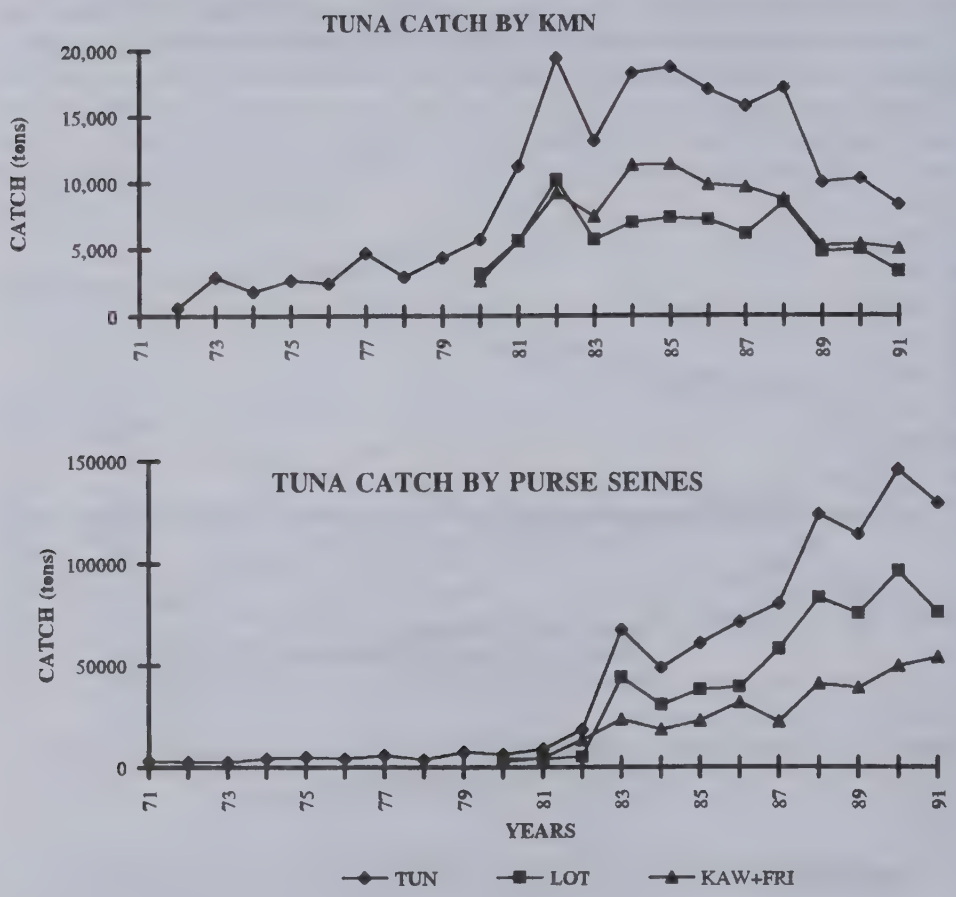

Figure 4. Catch of small tunas by species and gear type in the Gulf of Thailand, 1971-91. TUN=total tunas, LOT=longtail tuna, KAW+FRI=kawakawa and frigate tuna.

3.4 Catch and Effort

Catch and effort statistics of Spanish mackerel drift gillnet and purse seine are available from 1972 to 1991. The units of fishing effort used to observe trends in catch are the number of boats and the number of fishing days.

Except for 1991, the number of fishing boats and number of fishing days for the Spanish mackerel drift gillnet fishery showed similar increasing trends throughout the period 1971-91 (Figure 5). Fishing effort reached a maximum of 398 boats, or 76,915

days, in 1988. Catch increased from 2,200 mt in 1972 to a peak of 19,400 mt in 1982, and stabilised until 1988. After 1988 the catch dropped to 10,000 mt, corresponding to the lower level of fishing effort.

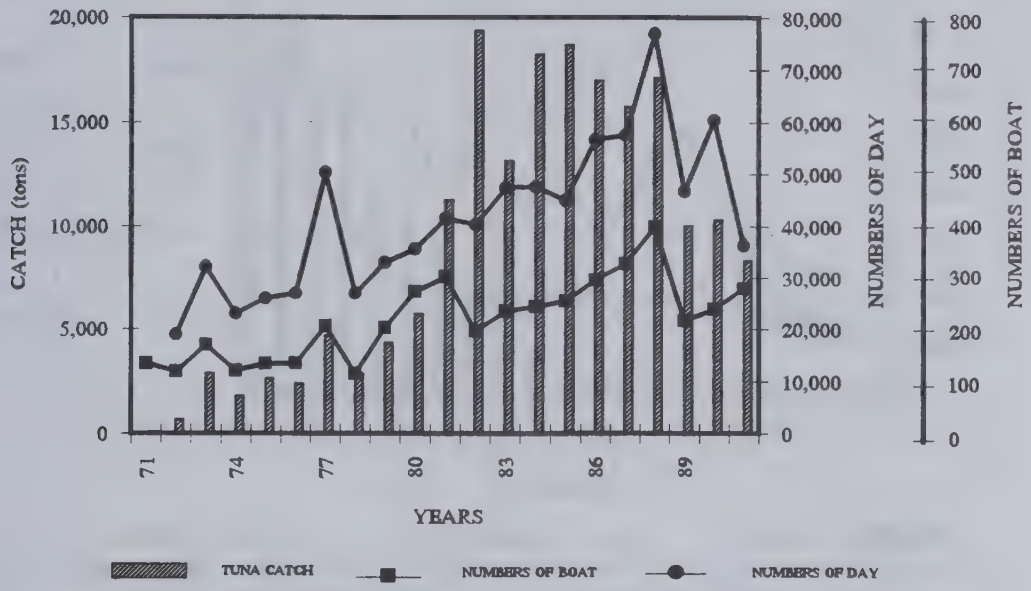

Figure 5. Catch and fishing effort of Spanish mackerel drift gillnet for small tunas in the Gulf of Thailand, 1971-91.

The catch of tunas by purse seines showed an increasing trend from 3,200 mt in 1971 to a maximum of 145,000 mt in 1990 (Figure 6). The number of purse seiners showed a gradual increase from 328 boats in 1971 to a maximum of 1,026 boats in 1991. By comparison, the number of fishing days showed wider fluctuations than effort, as measured by the number of boats. It was observed that an increase in purse seine effort occurred during the period from 1975 to 1978, while tuna catches increased remarkably after 1982. The reason for the increase in effort from 1974-78 does not appear to be tuna-related.

3.5 Catch Per Unit of Effort

The catch per unit of effort (CPUE, in kg/day) of combined Thai purse seine and luring purse seine from 1980 to 1991 shows increasing trends for both longtail tuna and small tunas (kawakawa/frigate tuna), especially after 1982 (Figure 7). This increase may be due to increase in fishing efficiency of purse seining due to experience, and also to expansion of the fishery into more productive fishing grounds in offshore waters.

The CPUE (kg/day) of the gillnet fishery shows declining trends for both longtail tuna and small tunas (Figure 8). The declines could be attributed to gear interaction. The trend in the gillnet catch rate contrasts with that of the purse seine fishery. It may be possible that the purse seine is much more efficient, thus making small tunas less available to gillnet that operated in the same area. Another possibility is that the purse seines by fishing further offshore catch the small tunas before they become available to the gillnets which normally operate in more coastal waters.

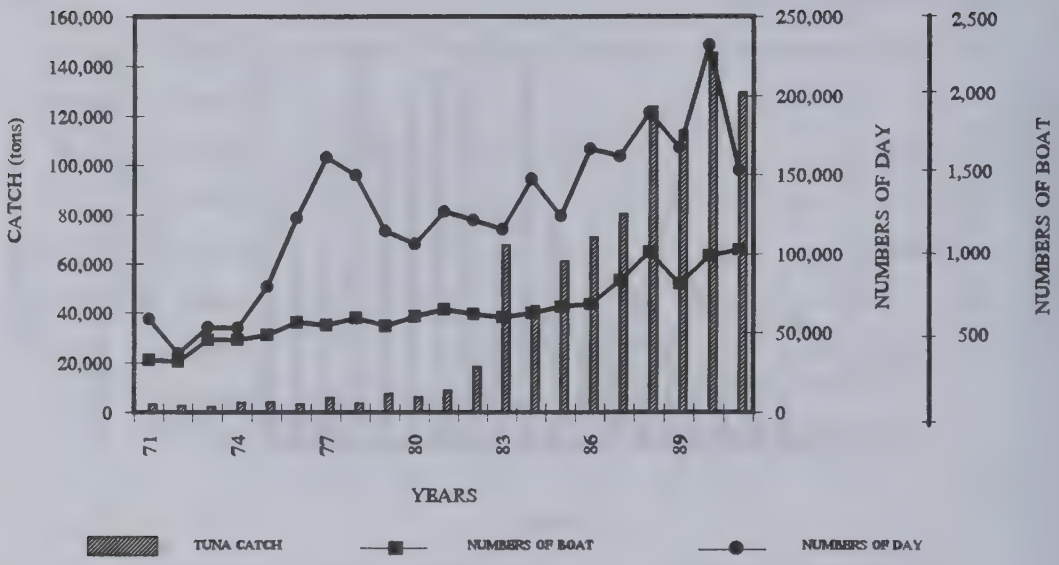

Figure 6. Catch and fishing effort of purse seine for small tunas in the Gulf of Thailand, 1971-91.

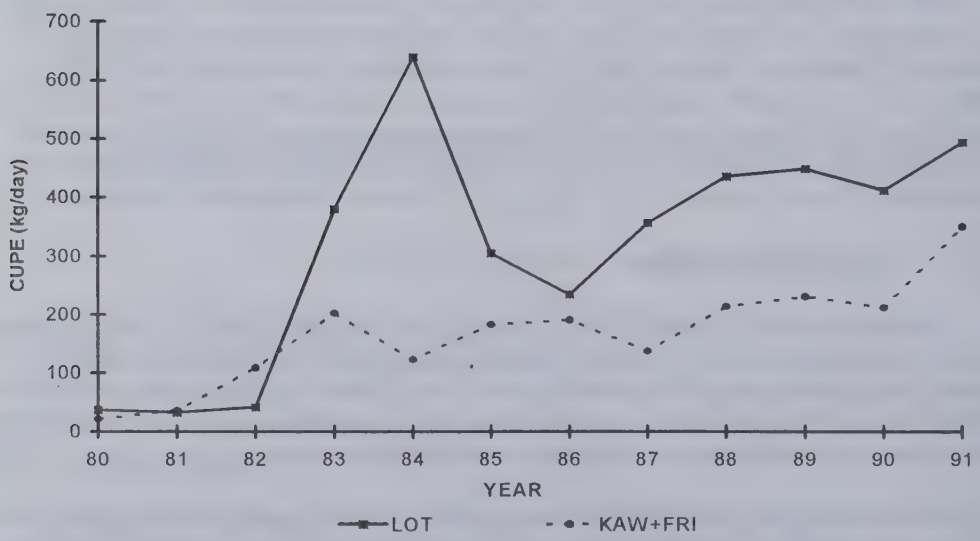

Figure 7. Catch per unit effort of purse seines in the Gulf of Thailand, 1980-91. LOT=longtail tuna, KAW+FRI=kawakawa and frigate tuna.

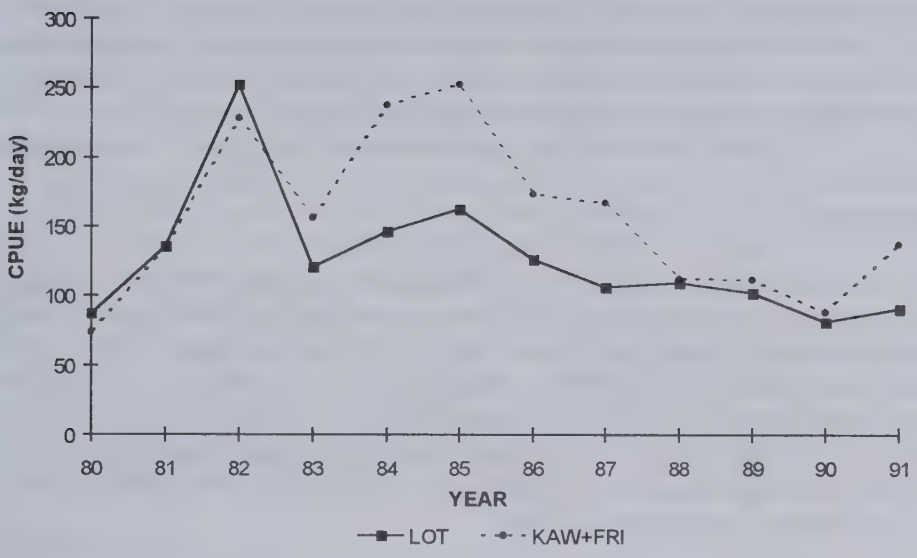

Figure 8. Catch per unit effort of Spanish mackerel drift gillnets in the Gulf of Thailand, 1980-91. LOT=longtail tuna, KAW+FRI=kawakawa and frigate tuna.

3.6 Change in Size Composition

The data on length frequencies distribution of small tunas had been collected through the sampling surveys at various fish landing sites since 1978. Analyses of size composition for each tuna species have been reported by Klinmuang (1981), Chuenpan (1985), Supongpan and Saikliang (1987), Yesaki (1994) and Pramokchutima (1993). The analyses indicated that the mean size of longtail tuna in the catch from drift gillnet decreased from 40.7 cm in 1979 to 38.5 cm in 1984, 38.7 cm in 1989 and 35.8 cm in 1993. The mean size in the purse seine catch decreased from 41.4 cm in 1983 to 38.8 cm in 1989. It was observed that the mean size and the decrease in size of longtail tuna caught by purse seines and drift gillnet was almost the same. The mean size of kawakawa caught by drift gillnet declined by 4.7 cm from 38.7 cm in 1979 to 34.0 cm in 1993. The mean size of frigate tuna captured by drift gillnet in 1979 was 35.9 cm; the mean size decreased to 32.2 cm in 1993.

The mean length in the catch of small tunas has declined throughout the period for which data are available. Longtail tuna showed the greatest effect from the fisheries. It may be possible that tuna resources have been heavily exploited, suggested by the decline in catch per unit of effort of both purse seine and drift gillnet. Other reasons for the difference in fish size may be the movement of the purse seine fleet to fishing grounds that are farther offshore, or the use of fish aggregating devices.

4. INTERACTION BETWEEN FISHERIES AND RESOURCES

Prior to 1980 the drift gillnet fisheries traditionally focused on Spanish mackerel, especially narrow-barred Spanish mackerel (*Scomberomorus commersoni*), while the purse seine fishery sought a variety of small pelagic species such as the Indo-Pacific mackerel (*Rastrelliger brachysoma*), Indian mackerel (*Rastrelliger kanagurta*), round scad (*Decapterus* spp.), sardines (*Sardinella* spp.) and other small pelagic fish. Purse seines and drift gillnet fisheries started to seek small tunas after 1980 to meet the demand of tuna processing plants.

Table 2 shows that the percentage of Spanish mackerel caught by drift gillnet showed a decreasing trend from 53.2% of the total catch in 1972, to a low of 12.7% in 1982 when fishermen began targeting small tunas. From 1983 to 1991, the percentage of Spanish mackerel ranged between 16.5 and 29.3%, while the small tunas showed an increasing trend over the years from 28.5% in 1972 to a high of 79.6% in 1982; thereafter small tunas ranged between 66.0 and 77.3%. The increase in the catch of small tunas in the latter period may be due to the expansion of fishing ground into the deeper waters where small tunas are more abundant than in shallow waters.

Small tunas caught by purse seines from 1972 to 1982 contributed less than 10% of the total catch. After 1982, small tunas became the target species and their percentage in the catch increased, reaching a high of 30.8% in 1990; subsequently, the catch of small tunas dropped slightly to 27.9% in 1991 (Table 3).

It was noted in general that the catch of small tunas by drift gillnets declined after 1982. This decline may be attributed to the low availability of small tunas to this fishing gear due to the increase in exploitation by purse seiners after 1982. The purse seiners gain an advantage over drift gillnetters because they are able to exploit small tunas farther offshore, catching these tunas before they become available to the drift gillnet fishery in coastal waters.

Taking into consideration that the CPUEs of longtail tuna and kawakawa/frigate tunas (Figures 7 and 8) show opposite trends between the drift gillnet and purse seines, it may be possible that interaction between these two fishing gears has occurred as a result of competition for the same resources in the same or adjacent areas.

The data on catch and CPUE between species groups of fish caught by purse seines and drift gillnet have been used to study the dynamics of these fisheries by applying the principal component analysis to assess the impact of the recent expansion of small tuna fisheries (Yanagawa, 1990). The correlation coefficients of catch and CPUE values, factor loading, eigenvalue, and factor score coefficient matrix were calculated.

The results of the analysis of the relationships between tunas and other species caught by purse seines showed that the increase in small tunas catch had a positive impact on anchovy, Indian mackerel, hardtail scad, black pomfret and Indo-Pacific mackerel, and it had negative effects on sardine and round scad. For drift gillnets, the catch of small tunas had a positive impact on Indo-Pacific mackerel and black pomfret, but it had a negative impact on Spanish mackerel and the jack-cavalla-trevally group.

It is presumed that the impact of catches of small tunas on other species can be attributed to difference in fish prices and structure of fisheries. The sardine fishery suffered the greatest negative effect from the increase of tuna fishery because of the change in target species of purse seines. Thai fishing vessels are designed for multi-purpose fisheries, thus it can easily change the target species and fishing gear depending on fishing conditions, fish prices and quantities of catch.

It should be stressed that the interaction between fisheries for small tunas using different fishing gears in the Gulf of Thailand is a growing problem. There seems to be a conflict between purse seiners and gillnetters that fish for small tunas in the same areas. Moreover, analyses of small tunas in Thai waters showed that they are widely distributed and the relative density appears to be greater in oceanic waters. This phenomenon may support the hypothesis that small tunas stocks in Thai waters may be from a common stock, or that they are from an intermingling of fish from waters of neighbouring countries. A careful examination of the catch, effort, CPUE, and species and size composition is planned to address the problem of interaction.

5. RESEARCH

Catch and effort statistics on small tunas have been collected from commercial purse seine and drift gillnet fisheries by the Fishery Statistics Sub-Division of the Department of Fisheries since 1972. The data have been separated into longtail and other small tunas (mainly kawakawa and frigate tuna) since 1979. The available statistics are not reliable enough for the studies on the status of stocks due to the multi-gear nature of the fisheries and the fact that different types of purse seines have been grouped together; these variables make allocation of effort for small tunas difficult. Another problem in gear classification is that the gear, and purse seines in particular, has been modified throughout the period, and this has created confusion for fishermen when registering their fishing gear with the Department of Fisheries. Many of the active purse seiners are not registered, so it may be presumed that fishing effort is underestimated.

Sampling of the commercial small tuna catch was initiated in 1977. Studies on the identification of tuna species found in Thai waters, distribution, species and size composition, mean length in the catch, reproduction, food and feeding, age and growth, and fisheries dynamics, have been made since that time. The results of those studies were compiled by Chullasorn and Martosubroto (1986). At present, attempts are being made to assess the state of tuna stocks based mainly on available catch and effort data.

Another source of information is the tuna sampling programme initiated in May 1987 with assistance from the Indo-Pacific Tuna Development and Management Programme (IPTP). The data collected for 2-1/2 years have been published in "Tuna sampling programme in Thailand" (IPTP, 1990).

Tuna resources have assumed a very important role for the marine capture fisheries of Thailand, especially since the increase in demand for tunas by the canning industry. Previous technical studies on the tuna resources that have been carried out do not seem to be adequate for present management and development purposes. Therefore, particular

attention has to be taken on the study on biology and other relevant information upon which to base as assessment on the state of exploitation of tuna stocks in Thai waters and high seas. As a general strategy, the Department of Fisheries continues to focus on research, development, extension, training, statistics, resource management and quality control for export development.

Since tunas are highly migratory and move from waters of one country to another, its stock must be shared by more than one country. Studies on the distribution and migration of tuna resources through tagging programme should be considered necessary. A joint tagging programme between Thailand and Malaysia was discussed at the second meeting of the Tuna Research Groups in 1987 and tagging was implemented in 1990 with the assistance of IPTP. Although the recovery rates of the tagged fish have been very low, the cooperation between countries of this tagging programme should be continued. International organisations in the region, e.g., SEAFDEC, should collaborate to achieve success of the tagging programme.

The study of the effects of environmental factors on the abundance of tunas was also conducted during the survey cruises involving purse seine operations. The results showed that temperature is an important factor in the aggregation of tunas schools. Schools were abundant in the upper boundary of the thermocline layers where temperatures varied from 13-30°C in depths ranging from 50-220 m. Such environmental studies should be continued and extended to the entire EEZ waters of Thailand to collect the basic information needed for future tuna fisheries development.

6. FISHERIES DEVELOPMENT AND PROSPECTS

The canning industry requires a substantial quantity of raw material (Table 3). With a view to develop the oceanic tuna fisheries by increasing production to meet the canneries' demand, fishing experiments have been conducted using pole-and-line, tuna longline and purse seining methods. During 1978 to 1981 an experimental pole-and-line fishing program was carried out by R/V PRAMONG 10 off Phuket, in collaboration with the FAO/UNDP. The results showed some promise for the development of tuna pole-and-line fishing in Thai waters. Experimental tuna longline surveys were also made off Phuket and Satul provinces, and in the Andaman Sea. The results obtained from these surveys revealed that there are sufficient tuna resources in the oceanic regime to encourage further development of tuna fisheries in the Thai EEZ. To date, Thai fishermen have paid little attention to these other fishing methods; purse seining is still the most popular fishing method.

Table 2. Catch composition by species groups of Spanish mackerel drift gillnet and purse seines in the Gulf of Thailand, 1972-91.

Year	Drift Gillnet					Purse Seine		
	Total Catch (tons)	Spanish Mackerel		Small Tunas		Total Catch (tons)	Small Tunas	
		Catch	%	Catch	%		Catch	%
1972	2,194	1,167	53.2	646	28.5	24,675	2,579	10.4
1973	7,633	3,496	45.8	2,880	37.7	44,286	2,190	4.9
1974	4,758	2,127	44.7	1,775	37.3	69,217	3,915	5.7
1975	6,556	3,101	47.3	2,632	40.1	74,979	4,124	5.5
1976	6,393	2,596	40.6	2,385	37.3	185,432	3,321	1.8
1977	9,796	4,009	40.8	4,577	46.7	421,728	5,925	1.4
1978	6,020	2,576	42.8	2,873	47.7	347,135	3,800	1.1
1979	9,432	3,914	41.5	4,328	45.9	261,457	7,547	2.9
1980	11,505	4,496	39.1	5,722	49.7	231,381	6,225	2.7
1981	18,434	5,082	27.6	11,218	60.8	312,353	8,691	2.8
1982	24,348	3,086	12.7	19,376	79.6	259,713	18,123	7.0
1983	18,523	3,738	20.2	13,105	70.7	369,535	67,314	18.2
1984	24,627	4,097	16.6	18,261	74.1	345,619	48,658	14.1
1985	25,172	4,158	16.5	18,694	74.3	418,106	60,758	14.5
1986	25,081	5,577	22.2	17,004	67.8	496,615	70,969	14.3
1987	23,541	5,273	22.4	15,735	66.8	493,188	80,042	16.2
1988	25,924	6,307	24.3	17,114	66.0	475,203	123,670	26.0
1989	14,999	3,617	24.1	10,000	66.7	449,270	113,939	25.4
1990	15,596	3,796	25.4	10,275	65.9	471,298	145,382	30.8
1991	10,740	3,150	29.3	8,304	77.3	464,083	129,461	27.9

Table 3. Demand for tuna: Total tuna used and proportion of domestic and imported tuna quantities from Thai canneries (1982-92). Source: Fisheries Statistics of Thailand, 1982-92.

Unit: tons

Year	Total Tuna Used	Domestic Catches	Imported Tuna
1982	40,320	27,722	12,598
1983	82,844	36,823	46,021
1984	146,120	60,420	85,700
1985	185,577	65,577	120,000
1986	288,724	83,346	205,378
1987	287,603	92,357	195,246
1988	357,087	82,176	274,910
1989	436,543	111,364	325,179
1990	474,107	114,768	359,339
1991	630,627	134,369	496,258
1992	530,259	100,149	430,110

The Department of Fisheries has launched a project of tuna resource surveys since 1987 by using R/V CHULABHORN to operate a large tuna purse seine in the South China Sea and the EEZ of Thailand's Andaman Sea. The surveys use FADs (fish aggregating

devices) to increase efficiency and reduce searching time. The surveys resulted in small tuna catches; the average catch rate was about 800 kg/haul, and consisted mainly of skipjack and yellowfin tunas. The small catches may be due to the lack of appropriate fishing technology and experience, and the unsuitability of the research vessel as a purse seiner. Although the R/V CHULABHORN was not designed particularly for purse seining, the surveys showed the possibility of developing and expanding fishing grounds for tunas in the offshore waters where Thai fishermen never fished before. The Department of Fisheries has built a new research vessel, the R/V MAHIDOL, designed along the lines of a super seiner. It is expected that this research vessel will solve the fishing capability problems of the R/V CHULABHORN. The exploration of new tuna fishing grounds and new fishing technique will be transferred to Thai purse seiners through extension and training.

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STUDIES OF INDONESIAN TUNA FISHERIES, PART 1: INTERACTIONS BETWEEN COASTAL AND OFFSHORE TUNA FISHERIES IN MANADO AND BITUNG, NORTH SULAWESI [1]

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ABSTRACT

Since 1990 an important offshore industrial tuna fishery has been established in northern Indonesian waters. This fishery is theoretically confined to the EEZ, but in practice it occupies large areas of territorial and archipelagic waters. Fishing is carried out by "sets" or groups of boats based on a single purse seiner, supported by carrier and smaller patrol boats. These groups fish around rumpon (FADs) deployed in waters from 200-4,000 m deep, and take substantial catches, most of which is landed directly into General Santos City and other southern Philippine ports. The offshore fishery lands more than 50,00 mt per year from waters around North Sulawesi and northern Irian Jaya. Coastal fishing is carried out for skipjack by two kinds of small pole-and-line vessels ("funai": 5-15 GT; "huhate": 20-30 GT) in North Sulawesi. The coastal fishery landed less than 9,000 mt of skipjack in 1989, the last year before large scale offshore fishing commenced. Data for Manado and Bitung (North Sulawesi) were analysed to determine the effects of the offshore fishery on the skipjack and yellowfin fisheries based in these cities. Skipjack CPUE fell in Manado (from 50-70 mt/boat/year in 1980 to less than 20 mt/boat/year in 1992) and Bitung (from more than 100 mt/boat/year in 1980 to about 60 mt/boat/year in 1990). Effort on skipjack in Bitung rose slowly from approximately 40 boats in 1986 to more than 100 boats in 1991, and then fell to under 35 boats in 1995; the decline was probably due to competition with the industrial fishery. Industrial CPUE fell from 0.69 mt of tuna/GT of effort/year in 1993 to 0.37 mt/GT in 1995. Available data are insufficient for a complete analysis of offshore-onshore tuna fishery interactions. Nevertheless it is likely that industrial, offshore tuna fishing impacted the coastal fisheries

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[1] The original paper presented at the Shimizu meeting ("The interaction between the artisanal and industrial tuna fisheries in the eastern Indonesia with special reference to Sulawesi Sea" by N. Naamin) has been revised extensively based on reviewers' comments. The present paper represents one segment of the original paper.

in Manado and Bitung by reducing the amount of skipjack and yellowfin available to the coastal fishery.

1. INTRODUCTION

Since 1990 there has been increasing concern about interactions between the Indonesian coastal and industrial yellowfin and skipjack fisheries. The Indonesian industrial fisheries appear to have been impacted by the large industrial fishery developed primarily by large Philippine companies working in the Sulawesi Sea and elsewhere in Indonesian waters (Mathews and Monintja, 1996). This new Philippine fishery is based on large purse seiners operating around fish aggregating devices (FADs) called "payao" in the Philippines and "rumpon" in Indonesia.

Fisheries based on rumpon have existed in Indonesia since time immemorial (Monintja, 1993). Rumpon affect skipjack and yellowfin catchability and abundance. They may also make the stocks more susceptible to overfishing (Mathews and Monintja, 1996). Effects of rumpon on tuna fishing must be taken into account when addressing some of the concerns being raised about the coastal and offshore tuna fisheries in the Sulawesi Sea and elsewhere in Indonesian waters.

Recent studies on tuna fisheries in and around the Indonesian province of North Sulawesi have produced some of the data that are needed to identify:

1. interactions between coastal (Indonesian) and offshore (largely foreign) fishing fleets targeted toward skipjack and yellowfin;

2. some interactions between rumpon, involving fishing gear used to catch tunas and small pelagic fish, the latter mostly scad; and

3. changes in yellowfin abundance, especially on fishing grounds along the north coast of Gulf of Tomini.

All of these issues must be understood if the relationship between Indonesian coastal and offshore tuna fisheries is to be addressed. Two short papers cover the above subjects: this study covering item 1, and Mathews et al. (1996) addresses items 2 and 3. A third study is scheduled to examine the effects of rumpon on catch rate in the EEZ in the Biak area north of Cendrawasi Bay in Irian Jaya. Comprehensive studies of the biological, economic and management implications have been made by Monintja and Mathews (1995), and Mathews and Monintja (1996).

2. METHODS AND DATA SOURCES

For the two studies reported here, secondary data were obtained during a total of eight weeks of surveys carried out in North Sulawesi Province. Data were obtained from (1) the Provincial Fisheries Service (Dinas Perikanan Tingkat I, i.e., Level One, located in Manado, the Provincial capital) and the county or city Fisheries Services (Dinas Perikanan Tingkat II, or Level II, located in Manado city, Bitung city, Gorontalo city, Gorontalo county, Tondano, capital of Minahasa county: and Kotamobagu, capital of Bolaang

Mongondow county; see Figure 1), and (2) interviews by C.P. Mathews and D. Monintja with experienced Fisheries Service personnel in all of these locations to assess the accuracy and reliability of data in the light of the sampling systems used, experience of key personnel and the facilities available. These authors also carried out additional interviews with experienced fishermen and fishing managers/operators in Kwandang, Inobonto, Tanawangko, Manado, and Likupang on the north and northwest coast. Bitung, Belang, and Gorontalo on the west and southwest coast were also visited. Access to points between Belang and Gorontalo (Figure 1) was precluded by floods and the destruction of roads and bridges during the recent rainy season in North Sulawesi. Results including qualifications about the accuracy of the data obtained are provided later, and (3) interviews with managers and fishermen from several Indonesian and foreign (Philippine and Taiwanese) fishing companies. All of the Indonesian and some of the foreign companies provided useful data and described their fishing strategies in detail.

Figure 1. Map of the study area. Shading indicates payao deployment.

3. RESULTS AND DISCUSSION

3.1 Boats and Gear

3.1.1 The coastal tuna fisheries for skipjack and yellowfin

Coastal tuna fishing has been carried out in Indonesia since historical periods using traditional vessels and a wide variety of gear. During the 1950s, pole-and-line fishing was introduced in North Sulawesi; data on catch and effort are only available since 1976. These data are published annually in the Provincial Fisheries Statistics (Buku Tahunan Statistik Perikanan, Propinsi Sulawesi Utara, 1976-1994; Manado, Sulawesi Utara).

Data on effort were originally based on catch and effort surveys usually carried out at the Tingkat II level, but for some time Tingkat I data have been based on the number of new and extant fishing permits (izin). Effort data from some Tingkat II, e.g., at Bitung are, however, still based on annual surveys and were found to be reliable when checked by means of direct censuses carried out through fishermen interviews. Where differences between Provincial and city or county effort data were found, the latter were used as they were believed to be more accurate.

Landings data are collected at county or city (Tingkat II) offices and sent to the Provincial (Tingkat I) office where some adjustments are usually made. From about 1990 foreign vessels started to catch substantial quantities of skipjack and yellowfin in offshore waters; much of the catch was landed directly in ports of southern Philippines and Taiwan. Although all of these landings are supposed to be declared to authorities in Bitung, Fisheries Service personnel believe only a small proportion of actual offshore (mainly foreign) catches are declared. Therefore, it was not possible to separate the offshore (mainly foreign) from the coastal (entirely Indonesian) landings in Bitung.

Provincial data are supposed to include all of the landings from North Sulawesi waters, including those made by foreign vessels operating in the adjacent EEZ. However, because of incomplete reporting by foreign vessels and related data collection problems, it was not possible to obtain accurate estimates of either coastal or offshore (largely foreign) tuna landings for most of North Sulawesi from 1990 onwards; Philippine and other foreign vessels were licensed to operate in large numbers starting in 1990. Data prior to 1990 are not influenced by foreign landings.

These data problems complicate and introduce uncertainties in the assessment of the effects of foreign offshore landings on local (primarily coastal) landings. Where possible, city and county landings and effort data were used as they are based on surveys and direct observations. Provincial landings data were also used, while taking account the above mentioned problems where necessary.

3.1.2 Philippine rumpon

Large numbers of rumpon were introduced by Philippine operators into the Indonesian EEZ (i.e., offshore from 12 nm) in 1990. Around 200 rumpon were licensed and deployed off Manado and west of the Sangihe Islands (northern waters of Sulawesi), with additional

larger numbers of rumpon placed elsewhere in Indonesian waters in later years (Mathews and Monintja, unpublished report, PUSLITBANGKAN, Jakarta; Mathews and Monintja, 1996). Normally Philippine fishermen operate a purse seiner "set"[2] or "group" with each unit covering 10-20 rumpon. Each group 1 consists of one catcher vessel (40-450 GT) accompanied by 2-3 carrier boats and 1-2 searcher boats. The searcher boats patrol the rumpon primarily to identify those that have attracted tuna schools. Searcher boats may also assist catcher boats by using powerful lights to attract tuna at night, making the tuna more vulnerable to purse seining. Searcher boats are also sufficiently large to dissuade most coastal Indonesian boats from fishing near rumpon: many reports have been received showing that Philippine fishermen interpose their larger boats between the smaller Indonesian coastal vessels and the rumpon around which the skipjack and yellowfin tend to aggregate. Reports of attempts by large foreign boats to ram small coastal vessels may have arisen from such attempts at interposition. Catcher boats are directed by searcher boats to rumpon that have attracted large schools, and fish caught are passed directly to carrier boats for transport. Most catches are then sent directly to southern Philippine ports such as General Santos City. The searcher boats play a most important role as it takes some time for a rumpon which has provided a successful set (usually 5-25 mt; Monintja, 1993), to attract sufficient fish to justify a new set (usually five days or more are needed between sets around a rumpon). Routine patrolling ensures that catcher boats do not waste time searching around rumpon that have attracted only small schools of tuna. The support given by the rest of the group allows the catcher boats to spend most of their time fishing. Therefore, purse seiner groups have a much higher fishing power than purse seiners operating independently.

Philippine rumpon are normally located in waters 400-4,000 m deep, usually less than 3,000 m. In North Sulawesi waters this implies that many, if not all, rumpon are situated in or near coastal waters, i.e., from 12-15 nm (21-27 km) to a maximum of 50 nm (90 km) from the coast. In practise rumpon may be as little as 5-10 nm from the coast. In addition many Philippine-owned and operated rumpon are situated in territorial waters, e.g., the Maluku Sea, to the east of Sulawesi, and in the area between Sangihe and Talaud Islands, all of which are included in Indonesian territorial waters (Mathews and Monintja, 1996).

3.1.3 Taiwanese and other longliners

Since about 1990 there has been a very significant increase in the number of Taiwanese longliners operating in the Indonesian EEZ and in territorial/nusantara (internal, archipelagic) waters of Indonesia. These boats catch yellowfin and are also thought to compete with Indonesian coastal fishermen. Boats may be up to or in excess of 100 GT.

3.1.4 Indonesian vessels

Most of the skipjack pole-and-line vessels are small (<300 GT), and may include:

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[2] The term "set" is used in two distinct ways in the industrial tuna fishery: (a) a "set" may be a group of boats that combine to fish tuna; and (b) a "set" may be a single operation involving the laying and recovery of the purse seine net: i.e., a set may have a zero catch. The term "set" is reserved here for the second meaning.

- 5-15 GT vessels, locally called "funai" and using small numbers (about 10) of long poles (around 5-6 m long), or

- 20-30 GT pole-and-line vessels, locally called "huhate" and using larger numbers (20-30) of smaller poles (around 3-4 m long). The fishing power of one huhate is equivalent to about two funai.

Both funai and huhate vessels tend to operate within 20-30 nm of the North Sulawesi shore, often much closer. Some of the larger boats fish around rumpon further offshore, a few of which are owned by Indonesian operators. The GPS positions of more than 300 rumpon in Indonesian waters are provided by Mathews and Monintja (1996); position accuracy is reported to be less than 200 m).

Yellowfin are usually caught by small (<5 GT) boats operating handlines or troll lines. In addition, some longliners from 5-50 GT operate in Sulawesi waters. Many of the small boats are grouped into cooperatives ("plasma") that may be associated with particular fish processing plants in Bitung or elsewhere.

3.2 The Fisheries

3.2.1 Manado fisheries

Skipjack fishery

Data on Manado landings were taken from the Manado City Fisheries Service and are of two kinds: (a) market sales volume which include the species composition, and (b) the total Manado City landings for which species composition is not available.

Skipjack in Manado are taken by funai and by troll lines (pancing tonda). A conversion factor of 10 troll lines to one funai may be used. The conversion factor is based on fisherman and operator interviews and inspection of fishing units (Table 1). Some fish are landed in the Manado City Market, while some are distributed directly to restaurants, small smoking plants and other outlets.

By assuming arbitrarily that the same proportion of fish is landed outside and inside the Manado City Market throughout the time series, it was possible to estimate the amount of skipjack landed from 1985-1995 (Table 2).

Catch and effort data for the Manado skipjack fishery are summarized in Table 3. The catches show levels of 1,000-2,000 mt/year, peaking in 1986-87 (Table 3, Figure 2). After large numbers of rumpon were introduced by Philippine companies in 1990, the catches fell to 900 mt (1990) and then to <600 mt (1992). There was a small increase in landings from 1993-95, probably caused by coastal fishermen working from small handline boats around foreign rumpon. The CPUE was generally high (40-80 mt/standard funai-pole-and-line boat) prior to the installation of rumpon in 1990. From 1990-95, the CPUE fell to about 15-25 mt/standard pole-and-line boat. This suggests that there was a distinct reduction in catch rates due to competition between coastal and foreign offshore fishermen operating around Philippine-owned rumpon.

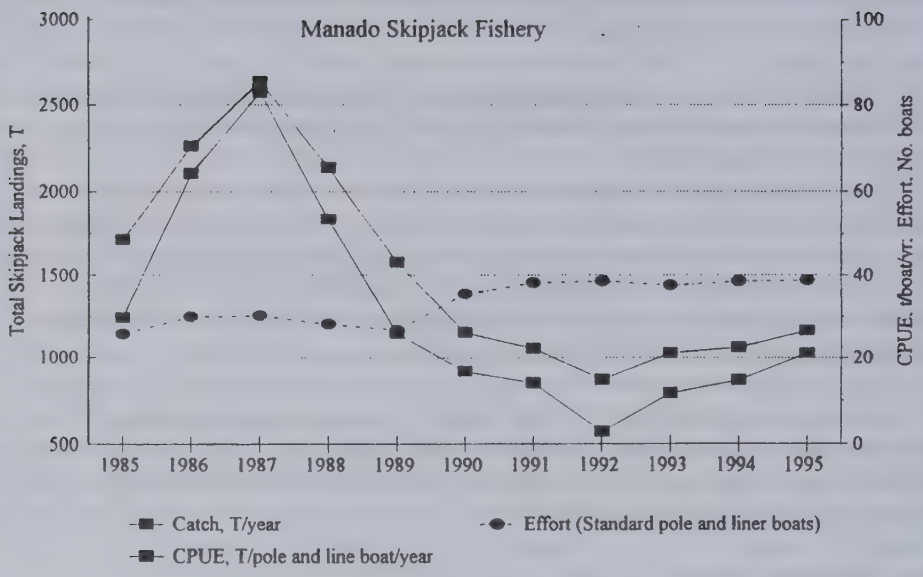

Figure 2. The Manado skipjack tuna fishery: catch (lower boxes), effort, and CPUE.

Table 1. Manado skipjack tuna fishery: estimated of total effort.

	a No Pole and Line boats	b Troll Lines	c Total nominal effort (pole and liners)
1985	10	156	25.6
1986	10	198	29.8
1987	14	161	30.1
1988	16	120	28.0
1989	17	96	26.6
1990	25	104	35.4
1991	25	132	38.2
1992	25	135	38.5
1993	24	135	37.5
1994	25	135	38.5
1995	20	187	38.7

NB: 10 troll lines are equivalent to one Funai type of pole and line boat (see text).
c = a+(b/10)

Yellowfin fishery

It was not possible to identify an unequivocal effort measure for the yellowfin fishery which uses handlines, because effort data for pelagic and demersal hook-and-line fisheries are not recorded separately. Table 4 and Figure 3 show the estimated landings data. Yellowfin are taken by small handline boats in shallow waters or sometimes around rumpon. Foreign fishermen tend not to prevent small handliners from targeting yellowfin around rumpon as this species is not taken in large numbers by purse seiners operating

around rumpon near Manado. Yellowfin landings peaked in 1990-91, at about 500 mt/year, and then landings fell to 349 met in 1995.

Table 2. Manado skipjack fishery: estimated landings.

	Estimation of total skipjack landings						
	a	b	c (from d)	(c/b)xa	d	e	e/d
	Skipjack Catch, T (market)	Total Catch (all spp),T (market)	Total Marine Catch (all areas, spp) T	Total Skipjack Catch, All areas	Total marine Fish t	Total Fish t	Ratio
1985	228.1	1150.4	6253.5	1240.0	6253.5	6253.5	1.0000
1986	400.5	1280.1	6718.2	2101.9	6718.2	6718.2	1.0000
1987	423.9	1107.7	6724.9	2573.5	6724.9	6724.9	1.0000
1988	263.7	985.5	6862.1	1836.1	6862.1	6862.1	1.0000
1989	204.8	1151.3	6432.3	1144.2	6432.3	6432.2	1.0000
1990	176.4	1100.4	5731.0	918.7	5731.0	6026.0	1.0515
1991	124.0	900.3	6155.1	847.5	6155.1	6497.8	1.0557
1992	105.3	1103.7	5968.9	569.7	5968.9	6357.3	1.0651
1993	151.2	1171.3	6104.1	788.1	6104.1	6832.4	1.1193
1994	139.7	1005.6	6227.5	865.5	6227.5	7062.9	1.1341
1995	130.2	784.3	6181.0	1026.4	6181.0	7010.0	1.1341

NB: Negligible amounts freshwater fish were landed into Manado prior to 1989.

3.2.2 Bitung fisheries

Skipjack fishery

Skipjack in the Bitung fishery are mostly caught by the large pole-and-line boats (huhate). Only the effort data of the Bitung skipjack fishery were judged to be unbiased (Appendix 1, Table A1) and show a fluctuating but generally steady effort from 1980-89, with fluctuating but generally declining CPUE (Table 5, Figure 4). This implies:

1. coastal effort was not sufficient to impact the abundance of that part of the skipjack stock accessible to coastal fishing; and

2. the CPUE of the coastal fishery from 1980-89 was probably responding to other influences, e.g., foreign effort on the stock (not including Philippine rumpon at this time), or to environmental parameters.

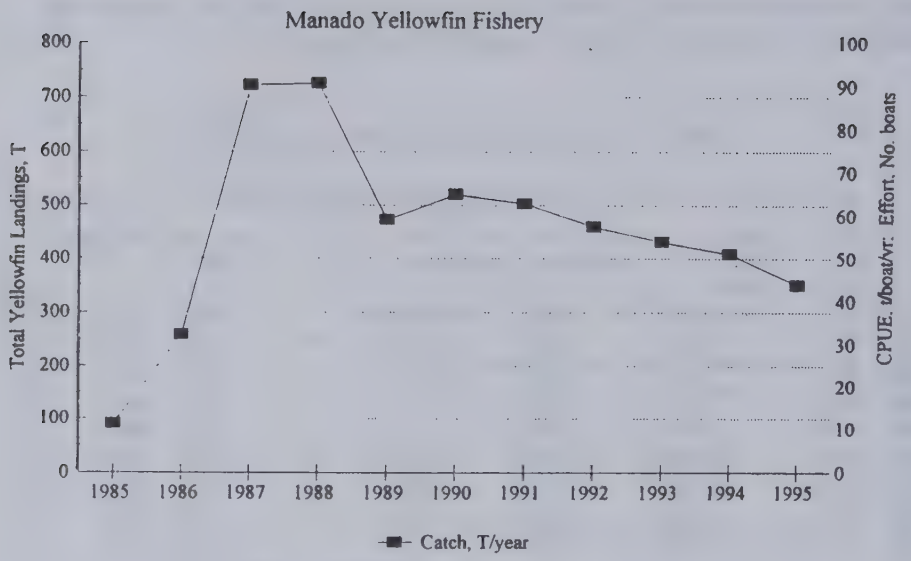

Figure 3. Manado landings of yellowfin tuna.

Table 3. Manado skipjack tuna fishery: catch, effort and CPUE.

	Catch T/year	Effort (in standard Pole and Line Boats)	CPUE T/Boat year
1985	1240 0	25 6	48.44
1986	2101.9	29 8	70 53
1987	2573.5	30 1	85.50
1988	1836.1	28.0	65.57
1989	1144.2	26.6	43.01
1990	918.7	35.4	25.95
1991	847.5	38.2	22.18
1992	569.7	38.5	14.80
1993	788.1	37.5	21.02
1994	865.5	38.5	22.48
1995	1026.4	38.7	26.52

NB: In Manado City pole and liners ore of the "funai" type (see text for desciption).

Table 4. Manado yellowfin tuna fishery: catch, effort and CPUE.

	a Yellofin Catch, T (market)	b Total Catch (all spp), T (market)	c (from d, Table 2) Total Manne Catch (all areas, spp) T	(c/b)xa Total Yellwofin Catch, All areas
1985	16.49	1150 4	6253.5	89.6
1986	49.19	1280.1	6718.2	258.1
1987	119.1	1107.7	6724.9	722.8
1988	104.1	985.5	6862.1	725 1
1989	84.6	1151.3	6432.3	472.9
1990	99.9	1100.4	5731.0	520.3
1991	73.6	900.3	6155.1	503.4
1992	85.0	1103.7	5968.9	459.6
1993	82.8	1171.3	6104.1	431.6
1994	66.0	1005.6	6227.5	408.6
1995	44.3	784.3	6181.0	349.2

Table 5. Bitung skipjack tuna fishery: catch, effort and CPUE.

a	b	c	d = b/c
	All Sulawesi	Effort	CPUE
	T	(Standard Bitung pole/liners)	
1980	10383	87.97	118.03
1981	7479	96.48	77.52
1982	9834	104.56	94.05
1983	9606	113.79	84.42
1984	8492	112.80	75.29
1985	5942	95.52	62.20
1986	6617	84.89	77.94
1987	7478	116.78	64.04
1988	8543	122.58	69.69
1989	8647	142.20	60.80
1990	**12263**	**129.51**	**94.69**
1991	**12263**	**134.41**	**91.23**
1992	**15803**	**124.31**	**127.12**
1993	**18199**	**125.18**	**145.38**

BOLD: data include purse seiner (foreign) landings and effort,
These data ara not comparable with data prior to 1990, which do not include substantial foreign landings. See Table A1.

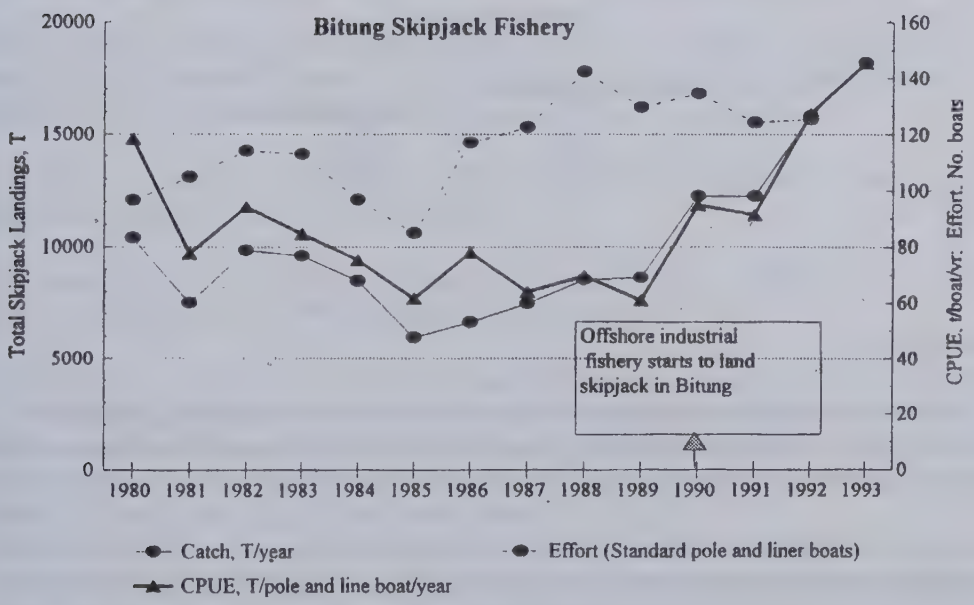

Figure 4. The Bitung skipjack tuna fishery: catch, effort and CPUE.

From 1991-95 many pole-and-line boats were withdrawn voluntarily from the fishery, and between 1993-94, another 30 boats were repossessed through bank foreclosures in fishermen who failed to meet debt requirements (Fisheries Service, Bitung, and interviews). Fishermen and boat managers were unanimous in blaming decreasing catch rates and declining catches for the reduction in number of pole-and-line boats. This

reduction started soon after the introduction of Philippine rumpon in waters adjacent to those occupied by coastal fishermen; the domestic fishermen were largely excluded from fishing around the rumpon by the sailing tactics of foreign fishermen.

Provincial data from 1980-89 (Table 5, column d) cover only the coastal Indonesian fishery as offshore foreign landings were low and were not directed towards North Sulawesi ports. From 1990 onwards an unknown amount of offshore foreign landings (probably large relative to coastal landings) was included in the North Sulawesi landings. The sharp increase in CPUE and estimated standard effort from 1990 onwards are therefore due to biases, and data from 1990 onwards are not comparable with data prior to 1990.

Table 6 and Appendix 2 (Tables A2 and A3) provide some estimates of CPUE for Philippine purse seine sets. The time series is short but does suggest that there was a sharp decline in overall CPUE from 0.69 mt of tuna/GT to 0.37 mt of tuna/GT. Similar trends were reported by company officials from about 1990-95; unfortunately, it was not possible to obtain data from 1990-93. The observed decreases in CPUE suggest that the industrial fishery working offshore may have reduced landings and CPUE in the near-shore fishery from 1993-94; a period when effort fell from 91 to 56 pole-and-line boats.

Table 6. CPUE for industrial purse seine sets operating in Indonesian EEZ, archipelagic and territorial waters.

Mean CPUE/Set/month				
1	2	3	4	MEAN CPUE/set/month
NA	NA	0.69	NA	0.69
0.32	0.38	0.62	NA	0.44
0.26	0.51	0.35	NA	0.37

Yellowfin fishery

Yellowfin are taken with handlines in the coastal fishery around Bitung. As in the Manado fishery, hook-and-line data for pelagic and demersal fish are pooled so that effort and CPUE cannot be estimated for yellowfin in the Bitung coastal fishery.

Estimates of yellowfin landings from the Provincial statistics are summarised in Table 7, together with landings for some other areas and for all of North Sulawesi. Data for Manado, Gorontalo and all North Sulawesi from 1990 onwards are not comparable with data prior to 1990 since the offshore, industrial landings caused a very marked increase in total landings. The decline in landings from 1990-91 was probably caused by competition between coastal and industrial landings; the increase from 1991-94 was probably caused by a substantial increase in *declarations* of yellowfin landings (not necessarily in *actual* landings) by foreign vessels fishing in the EEZ.

Table 7. North Sulawesi yellowfin tuna fishery (based on provincial data).

	Bitung	Manado	Gorontalo City	Gorontalo County	All Sulawesi
	T	T			T
1980	59	347	272	1091	3125
1981	80	837	1395	4657	7931
1982	138	648	1052	4360	7264
1983	206	769	1164	3656	6864
1984	288	772	1187	3541	6867
1985	236	493	842	3436	6010
1986	162	432	2278	3941	5901
1987	341	444	451	3655	6207
1988	810	435	1282	2618	6686
1989	1142	990	186	2987	7862
1990	2048	738	1593	2692	9063
1991					6429
1992	2165	636	1643	1476	7813
1993					12093
1994	14018	235	760	1122	18539
1995					

NB 1: Yellowfin landings are predominantly from the above areas.
NB 2: Decreasing yellowfin landings occur everywhere except in Bitung, where significant errors were introduced by offshore landings.
NB 3: Data in this table are taken from Provincial (Tingkat I), not from city and county statistics (Tingkat II) and may be less accurate (see text).

4. CONCLUSIONS

The number of Bitung boats targeting skipjack fell from more than 100 pole-and-line boats in 1991 to less than 35 boats in 1995; the decline occurred shortly after the introduction of Philippine rumpon into Indonesian EEZ and territorial waters.

By 1995 the industrial CPUE fell to 23% of 1993 levels; the decline was from a mean of 0.94 mt of tuna/GT to 0.22 mt of tuna/GT.

Industrial skipjack landings were at least 30,000-40,000 mt in 1994 and landings may have exceeded 50,000 mt in 1990 (Mathews and Monintja, 1996).

Total skipjack landings from North Sulawesi and Irian Jaya waters were at least 50,000 mt/year and may have exceeded 70,000-80,000 mt/year from 1990-95; prior to 1989 total landings were much lower at <25,000-30,000 mt/year (Mathews and Monintja, 1996). Industrial landings were over 50% of total landings taken in northern Indonesian waters, perhaps by a substantial margin from 1990 onward.

It is likely that industrial effort expended around rumpon by foreign boats competed with and reduced coastal skipjack landings around Bitung and Manado, the principal fishing ports for skipjack.

Effort and CPUE data for yellowfin are lacking for Bitung and Manado (but see Mathews et al., 1996a). Manado yellowfin catches declined after the introduction of rumpon in 1990.

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APPENDIX 1

Provincial vs City and County Data Sets

Table A1 summarises available catch and effort data for the skipjack fishery in Manado and Bitung (where most of the Indonesian skipjack landings and effort in North Sulawesi are concentrated) and for all North Sulawesi. Effort data for Bitung are the most accurate; the data were tested in 1995 by means of direct census based on fisherman interviews. The number of pole-and-line boats counted by name during this census (37 boats) was in close agreement with the preliminary estimate (about 30 boats) provided informally by the Fisheries Service in Bitung. Manado and Provincial effort estimates were less accurate. Bitung effort was therefore used to standardise skipjack effort for the entire time series.

North Sulawesi landings data form 1990 onwards included foreign landings. An attempt to clarify the data series by adjusting total recorded landings for skipjack exports (all believed to be made from foreign landings) failed to give results in accord with the experience of the fishermen who reported lower pole-and-line landings from 1992, leading directly to a reduction in number of boats. The data for the period from 1990 onwards (Table 5, columns b-d) are biased by unknown amounts of landings from foreign vessels. These landings are probably only a small portion of total foreign catches made in Indonesian waters; they are probably large relative to total North Sulawesi coastal landings and so a cause of serious bias in estimates of coastal landings. Derived data for CPUE (Table A1, i-k, o) and for total standardised effort (Table A1, column l) will also be biased and cannot be used in any assessment. Only effort data for Bitung are known to be unbiased.

Table A1. Catch and effort data for the skipjack tuna fishery in Manado, Bitung and North Sulawesi.

NB. ALL DATA FROM BUKU STATISTIK PERIKANAN TAHUNAN PROPINSI SULAWESI UTARA, (North Sulawesi Province Fisheries Statistics, Manado, North Sulawesi); unless indicated

ANCILARY DATA, not used in the assessment

North Sulawesi Skipjack Fishery (Unadjusted)

a	b	c	d	e	f	g	h	i	j	k	l = (d/i)	m	n	o = (n/k)
	Bitung	Manado	All Sulawesi	Bitung Effort	Manado Effort	All Sulawesi Effort	Bitung Effort	CPUE Bitung	CPUE Manado	CPUE All Sulawesi	Standard Effort All Sulawesi	Exports###	All Sulawesi (Adj. for Exports)	adjCPUE
	T ***	T ***	T ***	(pole/line)	(pole/line)	(pole/line)	(pole/line)	T/boat.year	T/boat.year	T/ boat.year	Bitung pole/liners	T	T	T/boat year
1980	7790.1	169.0	10383.4	66	14	198	66	118.03	12.07	52.44	87.97	0	10383	118.03
1981	5116.1	449.5	7478.8	66	13.3	186	66	77.52	33.80	40.21	96.48	0	7478.8	77.52
1982	6583.6	345.8	9833.6	70	13.3	174	70	94.05	26.00	56.51	104.56	0	9833.6	94.05
1983	5909.7	869.0	9606.4	70	13.3	159	70	84.42	66.84	60.42	113.79	0	9606.4	84.42
1984	4893.6	891.2	8492.3	65	13.3	155	65	75.29	67.01	54.79	112.80	0	8492.3	75.29
1985	2985.6	807.7	5941.5	48	13.3	138	48	62.20	60.73	43.05	95.52	0	5941.5	62.20
1986	3195.7	1020.0	6616.9	41	13.3	132	41	77.94	76.69	50.13	84.89	0	6616.9	77.94
1987	3073.7	1372.2	7477.9	48	13.3	140	48	64.04	103.17	53.41	116.78	0	7477.9	64.04
1988	3972.6	3398.4	8543.1	57	11	141	57	69.69	308.95	60.59	122.58	1513	7030.1	57.35
1989	4073.9	1330.2	8646.5	67	15	151	67	60.80	88.68	57.26	142.20	2290	6356.5	44.70
1990	7480.7	1932.9	12263.4	79	43	161	79	94.69	44.95	76.17	129.51	2296	9967.4	76.96
1991	9397.0	1893.8	12263.0	87	28	155	103	91.23	67.64	79.12	134.41	826	11437	85.09
1992	11313.9	1854.7	15802.9	134	43	215	89	127.12	43.13	73.50	124.31	3577	12226.9	98.35
1993	*13229.6*	*1815.6*	18199.2				91	145.38			125.18	4878	13321.2	106.41
1994	22030.9	717.8	26553.3	87	28	155	56	393.41	25.64	171.31	67.50		26553.3	393.41
1995							*33.5*	0.00						

NB(A): Skipjack effort is expended mostly in Bitung
(i) estimated from Provincial data; (ii)from fisherman surveys in Bitung City.
NB(B): Datum for Bitung effort in 1980 was erroneously given as 166 boats.
NB(C): Bitung CPUE (T/boat.year) was used to standardise effort.(i,n,o).

BOLD: from (e).
BOLD + Italics: estimated as mean of values identified in NB(A).
Underlined: interpolated *Underlined+Italics: extrapolated*
***Unadjusted for exports (= Philippine and other foreign landings)
###Exports estimated from data on frozen, smoked, fresh and sashimi products included in landings by Dinas Perikanan, but not landed by pole and liners

APPENDIX 2

Industrial Catch, Effort and CPUE

No data on total Philippine catch and effort from Indonesian EEZ and territorial waters are available. Data from one Philippine company which operates purse seine sets were made available and were used to estimate industrial CPUE (Table A2). The structure of a purse seine set is described in Table A2 and in the text. Table A3 summarises the data on Philippine industrial fishing in the Indonesian EEZ.

Table A2. Fishing power of Philippine purse seine fleet. A standard set is composed of one catcher, 2-3 carriers and 2-3 light boats.

Set1	GT	HP
Catcher	45.90	195.00
Carrier	35.01	195.00
Carrier	36.78	190.00
Lightboat	5.47	70.00
Lightboat	4.96	65.00
Lightboat	5.47	220.00
Total	132.19	935.00
Set2		
Catcher	86.34	220.00
Carrier	31.40	250.00
Carrier	28.10	195.00
Carrier	64.74	195.00
Lightboat	5.97	65.00
Lightboat	5.97	18.00
Lightboat	13.87	65.00
Total	236.19	1008.00
Set3		
Catcher	44.61	250.00
Carrier	34.60	220.00
Carrier	66.44	220.00
Lightboat	5.47	150.00
Lightboat	4.82	65.00
Lightboat	17.76	190.00
Total	173.70	1096.00
Set4		
Catcher	49.22	220.00
Carrier	57.00	190.00
Carrier	57.33	190.00
Lightboat	5.47	65.00
Lightboat	7.39	190.00
Lightboat	4.86	65.00
Total	181.27	910.00
Set5		
Catcher	49.76	220.00
Carrier	30.71	180.00
Carrier	28.35	100.00
Lightboat	14.15	110.00
Lightboat	11.26	80.00
Lightboat	8.57	120.00
Total	142.81	810.00

Set6		
Catcher	154.65	200.00
Carrier	96.43	195.00
Carrier	96.43	195.00
Lightboat	9.48	65.00
Lightboat	14.59	80.00
Lightboat	15.92	100.00
Total	387.50	835.00
Set7		
Catcher	54.29	335.00
Carrier	60.80	250.00
Carrier	27.07	190.00
Lightboat	12.60	65.00
Lightboat	6.73	65.00
Lightboat	16.80	225.00
Total	178.29	1130.00
[illegible]		
Catcher	155.90	425.00
Carrier	51.20	190.00
Carrier	40.25	250.00
Lightboat	10.37	190.00
Total	257.72	1055.00
Set9		
Catcher	134.73	365.00
Carrier	65.52	290.00
Lightboat	45.94	190.00
Lightboat	12.27	150.00
Total	258.46	995.00
Overall	1948.13	8773.00
Set10	216.46	974.78

NB: Set10 estimated as (Overall/9)

Table A3. Catch (mt) and CPUE (total gross mt/set) for Philippine purse seine fishery in offshore Indonesian waters (N EEZ), 1993-95.

		1993			1994									1995								
	Total GT	Jul	Aug	Sep	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept
Set1	132.19	45.5	176.5	199	18.085	21.667	66.421	38.496	20.465	13.029	139.099	26.071	141.344	24.96		71.177	142.938	152.668				
		0.34	1.34	1.43	0.14	0.16	0.50	0.29	0.15	0.10	1.05	0.20	1.07	0.19		0.54	1.08	1.15				
Set2	234.19	112.1	13.8		76.907	73.468	104.397	69.985		12.582	8.12	42.514	156.074	24.414	71.242	129.152	124.497	127.726				
		0.47	0.06		0.33	0.31	0.44	0.29		0.05	0.03	0.18	0.66	0.10	0.30	0.55	0.53	0.54				
Set3	173.70	169.2	61		26.934	62.092	99.135	173.622	131.258	21.113	211.347	10.437				90.93	124.09	51.427	162.582	72.48	115.433	10.114
		0.87	0.35		0.16	0.36	0.57	1.00	0.76	0.12	1.22	0.06				0.67	0.71	0.30	0.94	0.42	0.66	0.06
Set4	181.27	39.5	128.2	271	22.53	32.969	84.854		58.977	121.884		247.535	188.238						27.442	87.558	92.078	15.408
		0.22	0.71	1.50	0.12	0.18	0.47		0.33	0.67		1.37	0.93						0.15	0.48	0.51	0.09
Set5	142.81																		58.97			
																			0.41			
Set6	387.50																96.447	104.183	55.091	113.652	15.722	176.516
																	0.22	0.27	0.14	0.29	0.04	0.46
Set7	178.29	113.5	98.9	54.6	40.643	99.582	87.451	83.171	84.023	91.278	99.737	113.604	43.3	20.85		46.961	75.36	18.6	66.75	71.79	87.729	74.82
		0.64	0.54	0.36	0.23	0.56	0.49	0.47	0.47	0.51	0.56	0.64	0.24	0.12		0.26	0.42	0.10	0.37	0.40	0.36	0.42
Set8	257.72														53.053	45.672	45.258	54.042			48.338	28.169
															0.21	0.18	0.18	0.21			0.19	0.11
Set9	258.46	147.063		117.19		116.742	33.256	110.533	108.886		122.247	111.285			54.994	57.047						
		0.57		0.45		0.45	0.13	0.43	0.42		0.47	0.43			0.21	0.22						
Set10	216.46													86.901	12.971			176.984	126.218	164.902	87.738	43.617
														0.40	0.06			0.82	0.58	0.76	0.41	0.20
N		6	5	4	5	6	6	5	6	5	5	6	4	4	4	6	6	7	6	5	6	6
Mean		0.54	0.60	0.94	0.19	0.34	0.43	0.50	0.35	0.29	0.67	0.48	0.73	0.20	0.20	0.37	0.52	0.57	0.43	0.47	0.36	0.22

NB: N = no of obeservations

Seasonal summary, 1993-95

	First Quarter			Second Quarter			Third Quarter			Fourth Quarter			Mean CPUE/Quarter				
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	1	2	3	4	MEAN annual CPUE/month
1993							0.54	0.60	0.94				NA	NA	0.69	NA	0.69
1994	0.19	0.34	0.43	0.50	0.35	0.29	0.67	0.48	0.73				0.32	0.38	0.62	NA	0.44
1995	0.20	0.20	0.37	0.52	0.57	0.43	0.47	0.36	0.22				0.26	0.51	0.35	NA	0.37
MEAN, months	0.20	0.27	0.40	0.51	0.46	0.36	0.56	0.48	0.63								

STUDIES OF INDONESIAN TUNA FISHERIES, PART 2: CHANGES IN YELLOWFIN ABUNDANCE IN THE GULF OF TOMINI AND NORTH SULAWESI [1]

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ABSTRACT

Yellowfin tuna are taken on four Tomini Gulf (North Sulawesi) fishing grounds around "rakit"(small shallow-water fish aggregating devices) targeted towards scads and small yellowfin and around "rumpon" (larger deep-water fish aggregating devices) targeted towards medium-sized yellowfin. In Gorontalo, yellowfin landings increased from 1988 to a peak of more than 1,500 mt in 1990; the landings then declined steadily until 1995. Landings in Tilamuta, Paguat and Marisa fluctuated, but tended to peak between 100 and 200 mt around 1990. The CPUE at Gorontalo peaked in 1990 and fell markedly from 1990 onwards in all four fisheries; in 1995 the CPUE fell to about 30% of 1990 level in Gorontalo and to less than 10% of the 1990 levels at Tilamuta, Paguat, and Marisa. The sharp decline in CPUEs coincided with the extension of intensive offshore fishing by tuna longliners (mostly from Taiwan) and with the introduction of large-scale offshore industrial purse seining (which targets skipjack but also takes substantial amounts of yellowfin) by Philippine boats around North Sulawesi in 1990. The marked decline in yellowfin abundance suggests that offshore fishing impacted the Tomini Gulf fisheries.

1. INTRODUCTION

Naamin et al. (1996, Part 1 of this study) assessed the effects of industrial fishing on the coastal tuna fisheries in Manado and especially in Bitung (North Sulawesi), giving special attention to the skipjack fishery centered in these ports. They noted several data problems, but concluded that foreign rumpon (FADs or fish aggregating devices) placed in Indonesian waters around 12-50 nm (nautical miles) from the coast, impacted the important

[1] The original paper presented at the Shimizu meeting ("The interaction between the artisanal and industrial tuna fisheries in the eastern Indonesia with special reference to Sulawesi Sea" by N. Naamin) has been revised extensively based on reviewers' comments. The present paper represents one segment of the original paper.

coastal pole-and-line fisheries for skipjack in Bitung and Manado. They were, however, unable to provide useful effort data for the coastal yellowfin fisheries based around Bitung and Manado. During surveys carried out in many smaller North Sulawesi fishing ports in the Gulf of Tomini (described by Naamin et al., 1996, Part 1 of this study) reliable data on yellowfin catch and effort were obtained. The object of this paper is to use these new data to estimate changes in yellowfin abundance after the introduction of rumpon into Indonesian waters in 1990.

2. DATA AND METHODS

Localities and data collection methods have been described by Naamin et al. (1996, Part 1 of this study). Data on gear, landings, and species composition were obtained through the cooperation of the Provincial Fisheries Service (Tingkat I, Manado), the Gorontalo City Fisheries Office and the Gorontalo County Fisheries Office also located in the city of Gorontalo. These organizations developed and executed regular landings and effort surveys for Tilamuta, Marisa, and Paguat since the mid-1980s. The fisheries in these areas are characterised by the presence of FADs used to attract tuna and scad. Detailed records of the number of FADs deployed were not kept in all study areas. Nevertheless, records on the number of handlines ("pancing ulur") and troll lines ("pancing tonda") deployed on each fishing ground are available and were used to estimate effort.

3. RESULTS AND DISCUSSION

The two kinds of FADs deployed in the Gulf of Tomini tuna fishing grounds include "rakit" and "rumpon".

3.1 Rakit

Rakit are small FADs usually made of traditional materials. They are located in shallow waters (50-200 m deep at most) within 5-10 nm (9-18 km) of the coast, usually no more than 10-20 nm (35 km) from the nearest fishing port. Rakit have been used in Indonesia since time immemorial (Monintja, 1993) and are know to have been used for more than 30 years in many areas around Sulawesi Island, especially North Sulawesi. New rakit exploitation areas have also been established more recently (Mathews and Monintja, 1996). Rakit attract three commercially important species:

1. Small yellowfin, mostly juveniles, are attracted in large numbers and are taken by small handline boats (5-10 m , 45-100 hp outboard engines).
2. Scad (*Decapterus* spp., called "layang" or "malalugis" in North Sulawesi). Scad are captured around rakit by small purse seiners, locally called "mini-purse seiners" or "pajeko". Pajeko are usually 10-15 m long boats carrying outboard engines of 45-120 hp, and laying nets less than 200 m long.
3. Small amounts of skipjack are taken by the pajeko as an interesting, but not very important scad bycatch; skipjack are marketed separately.

Rakit occur in all Gulf of Tomini tuna fisheries. Roughly equal amounts of scad and small yellowfin (about 30-80 cm FL, less than 5 kg/ individual) are landed by boats fishing around rakit.

3.2 Rumpon

Rumpon are larger FADs which are placed on deeper waters (usually 400-4,000 m) and located up to 50 nm from the coast; exceptions are in North Sulawesi where rumpon are usually located within 10-20 nm of the coast. Many rumpon are located in territorial or archipelagic waters (Mathews and Monintja, 1996). Fishing around rumpon is targeted towards tuna, mainly skipjack and yellowfin. The effects of rumpon on tuna fisheries have been studies in detail by Monintja (1993) and Monintja and Mathews (1995). In the Gulf of Tomini, rumpon occur only in the Gorontalo yellowfin fishery.

Although scad, and small amounts of small skipjack, are produced in the Gulf of Tomini fisheries, yellowfin is usually the prime target species. This is particularly the case for the Gorontalo yellowfin fishery where one company (PT Usaha Mina) uses high technology fish processing methods and targets the Tokyo fresh fish market. About 50 mt of fresh sashimi-quality yellowfin chunks are exported monthly; exports are made on Friday afternoon, arriving in Tokyo on Sunday morning in time for consumption at Sunday lunch. Prices obtained range from US$10-12/kg.

3.3 Effort Standardisation

Yellowfin are caught around rakit or rumpon principally from small boats with handlines. In some areas troll lines are also deployed and take small amounts of yellowfin. A standard handliner carries five handlines, each handline with at least five hooks of different size. Boats that troll usually carry around four troll lines. Based on experience and interviews with county and city fisheries service staff and fishermen, a conversion factor of four troll line boats to one handline boat was used. Therefore, the standard handline boat had a fishing power equal to 16 troll lines or five handlines. Available data on the catch and he number of handlines and troll lines were used to estimate effort in numbers of standard handline boats (Tables 1 and 2).

Table 1. Gorontalo yellowfin tuna fishery.

	Catch (mt)	Effort (HLyr)*	CPUE (mt/HLyr)
1988	1,282	574	2.23
1989	1,366	579	2.36
1990	1,593	501	3.18
1991	1,416	825	1.72
1992	1,388	1,235	1.12
1993	1,120	1,295	0.86
1994	854	1,293	0.66
1995	811	n/a	n/a

* HL = standard handline boat (see text)

Table 2. Tilamuta, Paguat and Marisa yellowfin tuna fishery, 1985-95.

LANDINGS (T), TILAMUTA Yellowfin Tuna FISHERY

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total Catch	Total Effort	CPUE	Effort: Handlines	Effort: Troll Lines
1985	18.0	24.9	21.2	32.5	19.0	10.9	14.4	14.6	13.8	18.4	22.6	17.1	227.4				
1986	17.9	8.7	14.1	22.8	19.7	16.5	19.1	19.7	37.7	30.7	30.2	31.3	258.4				
1987	4.6	4.9	34.8	8.6	10.0	7.6	6.3	5.7	4.1	5.1	6.7	7.6	106.0				
1988	18.1	30.1	23.3	26.2	29.3	22.1	8.5	3.2	8.6	8.8	7.6	11.6	197.4				
1989	8.9	17.9	13.5	20.2	13.7	9.9	8.8	10.7	8.5	12.1	15.3	18.2	157.7				
1990	10.1	6.2	14.7	9.7	15.6	17.6	18.6	15.4	10.6	20.9	19.3	12.6	171.3	**21.88**	7.83	105	14
1991	11.1	13.8	17.3	13.1	8.2	5.5	15.8	10.7	19.7	23.7	27.1	18.1	184.1	**24.88**	7.40	120	14
1992	0.0	0.0	0.0	10.8	8.4	5.8	15.8	11.3	11.4	13.2	7.7	11.3	95.7	**34.63**	2.77	165	26
1993	5.5	5.5	1.4	9.4	7.5	10.0	2.5	3.9	2.7	5.7	4.2	3.7	62.0	**40.81**	1.52	195	29
1994	2.6	1.4	4.5	4.5	4.6	2.4	1.3	4.5	2.2	4.7	6.5	4.1	43.3	**41.88**	1.03	200	30
1995	1.5	2.4	1.7	3.7	8.9	4.8	1.4	0.6	1.7	1.1	0.6	1.3	29.7	**47.19**	0.63	225	35
Total	98.3	115.8	146.5	161.5	144.9	113.1	112.5	100.3	121.1	144.4	147.8	136.9	1543.1				
%	6.37	7.50	9.49	10.47	9.39	7.33	7.29	5.03	7.85	9.36	9.58	8.87	100.00				

**Total Effort in number of standard handline boats = (Handlines/5)+(Troll lines/4x4). The same conversion was used for Paguat and Tilamuta.

LANDINGS (T), PAGUAT Yellowfin Tuna FISHERY

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	Total Effort	CPUE	Effort: Handlines	Effort: Troll Lines
1985																	
1986																	
1987																	
1988	0.0	0.0	12.1	7.9	4.9	1.3	2.6	7.5	7.9	1.6	10.6	3.8	60.2				
1989	3.4	19.0	20.8	8.0	7.0	16.0	9.9	5.1	6.5	6.8	5.1	2.2	109.8				
1990	0.5	0.0	8.0	4.1	11.3	6.6	1.9	1.2	2.6	7.1	9.1	3.6	56.0	**48.35**	1.16	83	508
1991	1.8	4.5	5.4	9.9	1.3	0.0	1.8	0.0	0.0	0.0	0.0	0.0	24.7	**57.16**	0.43	98	601
1992	0.8	0.0	0.0	0.4	0.7	0.2	0.1	1.3	0.0	0.2	0.1	0.1	3.9	**59.09**	0.07	102	619
1993	0.0	7.0	1.2	3.8	2.0	0.9	0.1	0.1	0.2	0.1	0.0	0.0	15.4	**61.55**	0.25	114	620
1994	0.0	2.0	1.8	2.9	4.1	2.0	3.5	2.4	3.0	6.3	9.0	3.1	40.1	**90.34**	0.50	202	639
1995	0.3	0.7	0.7	0.3	1.3	1.6	1.4	1.4	0.9	1.6	0.2	0.4	10.8	**87.33**	0.12	236	642
Total	6.8	33.2	50.0	37.3	32.6	28.6	21.3	19.0	21.1	23.7	34.1	13.2	320.9				
%	2.12	10.35	15.58	11.62	10.16	8.91	6.64	5.95	6.58	7.39	10.63	4.11	100.00				

LANDINGS (T), MARISA Yellowfin Tuna FISHERY

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	Total Effort	CPUE	Effort: Handlines	Effort: Troll Lines
1985	7.2	9.8	7.9	9.5	13.2	6.1	8.8	9.1	7.4	8.2	9.9	8.0	105.1				
1986	0.5	6.7	12.0	1.2	11.7	6.3	4.3	5.0	6.9	8.0	3.8	5.9	72.3				
1987	3.8	1.8	4.7	8.8	5.4	4.5	4.2	3.8	2.4	2.3	5.0	2.8	49.5				
1988	0.0	0.0	12.1	7.9	4.9	1.3	2.6	7.5	7.9	1.6	10.6	3.8	60.2				
1989	3.4	19.0	20.8	8.0	7.0	16.0	9.9	5.1	6.5	6.8	5.1	2.2	109.8				
1990	0.5	0.0	8.0	4.1	11.3	6.6	1.9	1.2	2.6	7.1	9.1	3.6	56.0	**15.60**	3.59	78	
1991	1.8	4.5	5.4	9.9	1.3	0.0	1.8	0.0	0.0	0.0	0.0	0.0	24.7	**98.00**	0.25	98	
1992	0.8	0.0	0.0	0.4	0.7	0.2	0.1	1.3	0.0	0.2	0.1	0.1	3.9	**118.00**	0.03	118	
1993	0.0	7.0	1.2	3.8	2.0	0.9	0.1	0.1	0.2	0.1	0.0	0.0	15.4	**143.00**	0.11	143	
1994	0.0	2.0	1.8	2.9	4.1	2.0	3.5	2.4	3.0	6.3	9.0	3.1	40.1	**176.00**	0.23	176	
1995	0.3	0.7	0.7	0.3	1.3	1.6	1.4	1.4	0.9	1.6	0.2	0.4	10.8	**193.00**	0.06	193	
Total	18.3	51.5	74.8	56.8	62.9	45.5	38.6	36.9	37.8	42.2	52.8	29.9	547.8				
%	3.34	9.40	13.62	10.37	11.48	8.31	7.05	1.86	6.90	7.70	9.64	5.46	100.00				

3.4 Catch, Effort and CPUE in the Gulf of Tomini Yellowfin Fisheries

Certain features are common to all four of the fisheries operating in the Gulf of Tomini:

1. Effort increased about two-fold between 1990 and 1995 for the Tilamuta and Paguat fisheries (Figures 1 and 2) and more than three-fold for the Marisa and Gorontalo fisheries (Figures 3 and 4).

2. Landings peaked at Gorontalo in 1990 (more than 1,500 mt; Figure 4), at Paguat and Marisa in 1989 (about 120 mt; Figures 2 and 3, respectively); and at Tilamuta from 1988-91 (about 200 mt/year; Figure 1).

3. The CPUEs fell markedly in 1995 to about one-tenth of the 1990 level at Tilamuta and Paguat (Figures 1 and 2, respectively) and to less than one-third of the 1990 level at Gorontalo; Figure 4). At Marisa (Figure 3) the CPUE in 1995 was very much lower than in any other fishery studied.

The sharp decline in CPUE occurred between 1990 and 1995 in all four fisheries. The only fishery for which CPUE data are available for the period prior to 1990 (Gorontalo) show increasing CPUE until 1990, then a sharp drop (Table 3, Figure 4). The decline in CPUE from 1990 onwards coincides with a marked expansion of offshore fishing by industrial purse seiners working around rumpon, and by markedly increased longliner effort (Mathews and Monintja, 1996).

Table 3. CPUE (mt/HLyr) in some Tomini Gulf fisheries.

	Tilamuta	Paguat	Marisa	Gorontalo
1988	-	-	-	2.23
1989	-	-	-	2.36
1990	7.83	1.16	3.59	3.18
1991	7.40	0.43	0.25	1.72
1992	2.77	0.07	0.03	1.12
1993	1.52	0.25	0.11	0.86
1994	1.03	0.50	0.23	0.66
1995	0.63	0.12	0.06	-

3.5 Conditions on Other North Sulawesi Yellowfin Fisheries

No effort data for yellowfin landings are available for the Manado and Bitung fisheries. Yellowfin landings in Manado declined from more than 700 mt/ year in 1987-88 to about 350 mt in 1995 (Naamin et al., 1996, Part 1 of this study, Table 3) and from 990 mt in 1989 to 234 mt in 1994 (Naamin et al., 1996, Part 1 of this study).

Provincial data for Bitung show that yellowfin landings *increased* from about 1986 onwards, contrary to observations in all other areas where landings *decreased*. The increase reported for Bitung (Naamin et al., 1996, Part 1 of this study) is probably an artifact arising from the inclusion in the Provincial (and local) data of substantial Taiwanese and other longliner landings from offshore waters. It is also likely that substantial yellowfin landings were reported for the Bitung area by the Philippine purse seiner fishery which started in Indonesian waters in 1990. Mathews and Monintja (1996) show that yellowfin provide about 30% of tuna catches made by ring netters and purse seiners around rumpon in both Philippine and Indonesian waters.

Reports from coastal fishermen at Kwandang, Inobonto, Tanawangko and Likupang on the north coast, and at Belang on the northeast coast (Naamin et al., 1996 Part 1 of this study, Figure 1) all indicate that yellowfin landings fell in recent years, while Bitung fishermen and managers also reported decreased coastal landings.

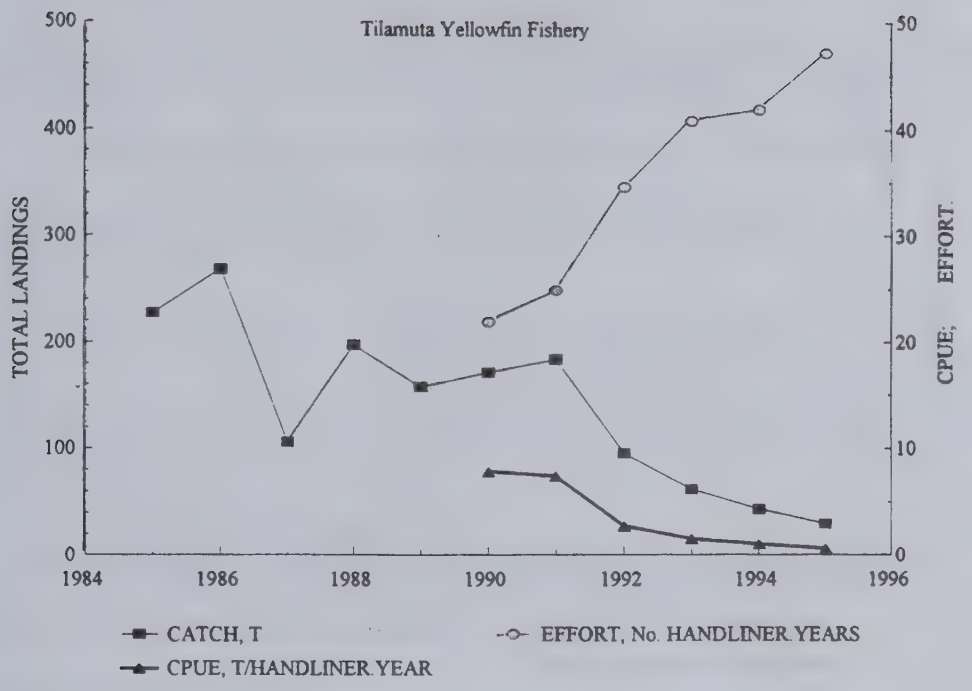

Figure 1. Catch, effort and CPUE in the Tilamuta yellowfin tuna fishery.

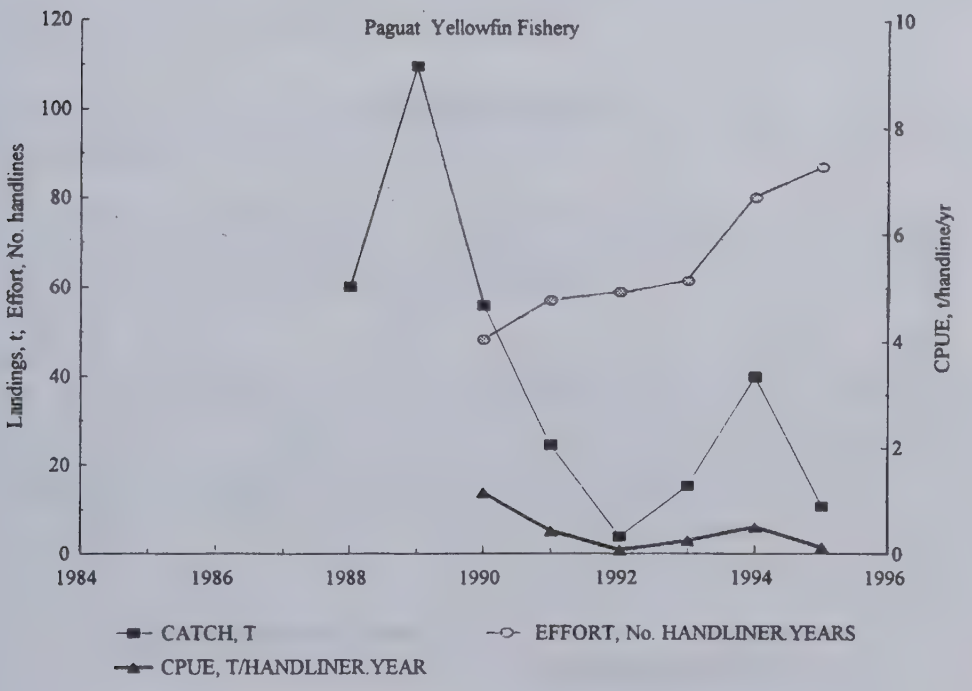

Figure 2. Catch, effort and CPUE in the Paguat yellowfin tuna fishery.

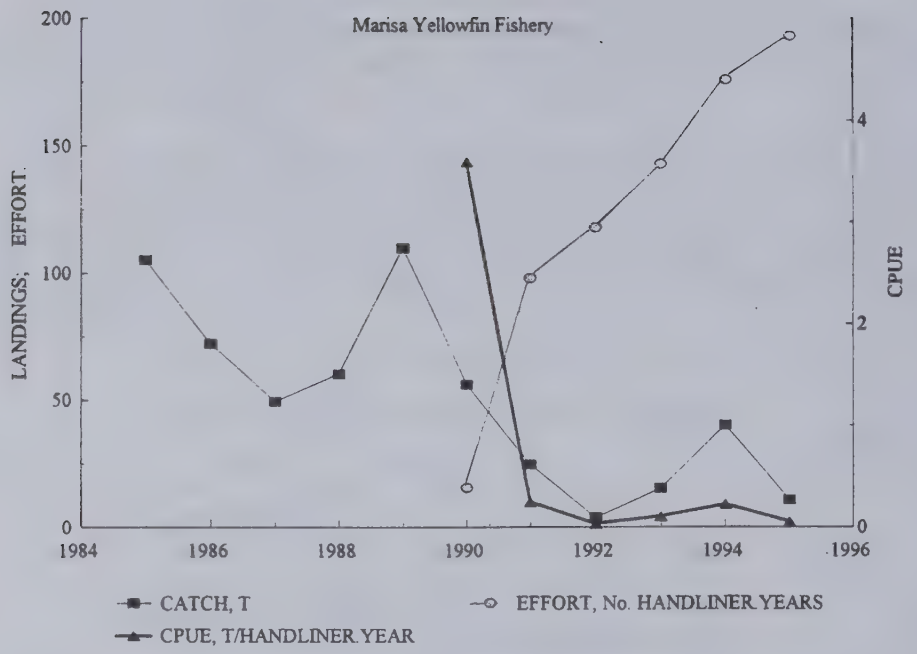

Figure 3. Catch, effort and CPUE in the Marisa yellowfin tuna fishery.

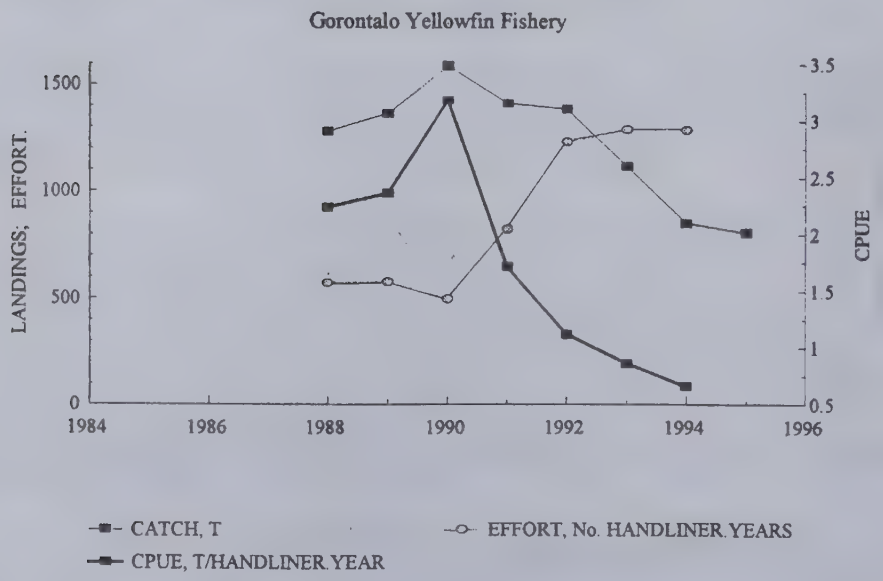

Figure 4. Catch, effort and CPUE in the Gorontalo yellowfin tuna fishery.

4. CONCLUSIONS

The sharp decline in CPUEs of the Tomini Gulf fisheries since 1990-91 coincided with and may have been caused by the sharp increase in effort expended on yellowfin by:

1) offshore industrial purse seiners from Philippines and other countries; and

2) increases in tuna longliners by Taiwanese and other vessels (Mathews and Monintja, 1996).

These increases in effort produced very large increases in landings by foreign fleets from the Sulawesi Sea, Malachi Sea and adjacent areas in Indonesian waters; these landings exceeded 50,000 mt/year (Mathews and Monintja, 1996). The very substantial industrial fishing activities may have reduced landings by the domestic coastal fisheries in the Tomini Gulf. Alternatively, the CPUEs (and abundance) may have fallen due to the effects of presently unknown environmental factors.

It is also possible that a combination of environmental and effort changes combined to impact the North Sulawesi coastal fisheries. In any case, concern about the current condition of the coastal yellowfin tuna fisheries in Indonesia is justified.

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WESTERN PACIFIC YELLOWFIN TUNA RESEARCH GROUP FINDINGS ON TUNA FISHERIES INTERACTIONS

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ABSTRACT

The Western Pacific Yellowfin Tuna Research Group has been coordinating research on the population biology of yellowfin tuna of the central-western Pacific Ocean since 1989. One of the Group's objective is to study the interaction among fisheries in the region. In August 1994, the Group reviewed results of longline-purse seine fisheries interaction studies conducted by members. It concluded that the sizes of yellowfin tuna caught by the fishing gears overlap, at least some yellowfin caught and tagged in surface waters are later recaptured by longline gear, and the longline-purse seine fisheries interaction appears weak within the central-western Pacific as a whole. This weak interaction is largely because the exploitation rate is currently modest, averaging 0.20. The Group also concluded that some localities in the region are experiencing substantially higher exploitation rates than this average and may be experiencing significant fisheries interactions at the local level.

1. INTRODUCTION

The Western Pacific Yellowfin Tuna Research Group (WPYRG) is an informal organization of scientists and fisheries officers studying the population biology of yellowfin tuna, *Thunnus albacares*, of the central-western Pacific Ocean (CWP). The Group's purpose is to exchange information and data, plan and cooperate in collaborative research projects, foster a common understanding of the condition of the yellowfin tuna stock, and offer scientific advice on fishery management issues. One of the Group's objectives is to evaluate interactions among the various fisheries that catch yellowfin tuna in the central-western Pacific Ocean.

In 1990, the Group reduced this objective into research questions. The first question that the Group chose to address was, what is the level of interaction between longline and purse seine fisheries on a region-wide basis? The Group felt that once this interaction was better understood, research could then focus on other more local fisheries interactions using the experience gained from this first study. Reported in this document is the progress made by the WPYRG with the longline-purse seine fisheries interaction study. More detailed information on the Group's findings is found in WPYRG meeting reports (WPYRG, 1993; 1994a; 1994b).

2. SCALE OF STUDY

The study area adopted by the WPYRG is a region bound on the north by 40°N, on the west by Australia and 120°E, on the east by 150°W, and on the south by 40°S (Figure 1). Within this area, there are various types and sizes of fisheries that catch yellowfin tuna as a target and as a bycatch species. In 1993, the fisheries caught approximately 397,000 mt of yellowfin tuna. Most were taken with purse seine (62%) and longline (16%) gears; consequently, these gears are often suspected of having major effects on the yellowfin tuna population and on other fisheries in the area. Hampton (1994), for example, showed that out of the 35 cases of tuna fisheries interactions issues identified in the CWP, only three do not involve purse seine or longline gears (Table 1).

This suspicion is reinforced by data on sizes of yellowfin tuna in the catches. Although different sizes of fish are caught by the different gears, the range of sizes taken by purse seine gear overlaps sizes taken by other gears (Figure 2). The USA purse seiners, for example, typically catch yellowfin tuna from approximately 35 cm fork length (FL) to 150 cm FL. Japanese longliners catch primarily large yellowfin tuna at sizes that overlap those of the purse seiners in the range of 60 cm FL to 150 cm FL. Within this overlapping size range, the purse seiners catch 5 to 8 times as many yellowfin tuna as longliners. Philippine ring net gear, on the other hand, catches primarily small yellowfin tuna in the range of 15 cm FL to 50 cm FL. Fish caught by this gear overlap somewhat sizes taken by purse seiners, but not sizes taken by longliners.

3. LONGLINE - PURSE SEINE FISHERIES INTERACTION

The WPYRG investigated the interaction between the large-scale purse seine and longline fisheries to determine the extent and level of the fisheries interaction. Studies were undertaken using three methods: (1) correlation analysis using catch-effort statistics, (2) movement and tag-returns analysis using tag-recapture experiments, and (3) qualitative analysis using biological information.

The first method was applied to time-series of fisheries statistics, building on results from earlier studies (Suzuki, 1994). Using Japanese longline data, catch-per-unit of effort (CPUE) of yellowfin tuna were computed and time-series trends analysed. The CPUE for the region as a whole indicated a sharp declining trend between 1959 and 1973 followed by a significant upward trend until 1979 before declining again to a low level (Figure 3). The sharp decline in the 1960s occurred well before the build-up of the purse seine fishery and associated surface catches (Figure 3). The more recent decline, on the other hand, occurred during the period of expansion of the surface fishery as well as during the period when the Japanese longline fleet switched to targeting bigeye tuna (Suzuki et al. 1977). Recent analysis that corrects for this switch in target species produces a stable CPUE trend since 1989 in the Japanese longline CPUE (Miyabe, 1994). Thus, analysis of CPUE data has not demonstrated a region-wide interaction between the two gears for yellowfin tuna.

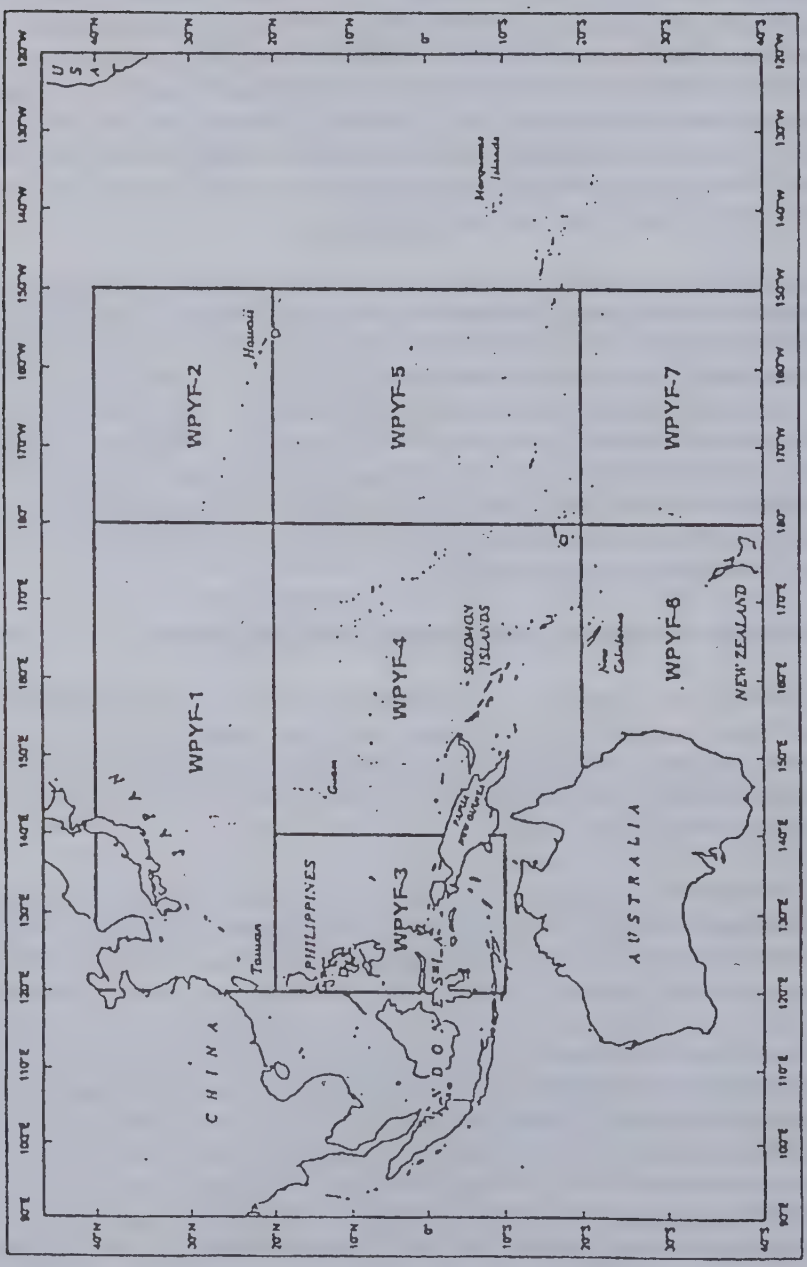

Figure 1. Western Pacific Yellowfin Tuna Research Group statistical areas.

Table 1. Catalogue of tuna fishery interactions issues in the western and central Pacific Ocean (from Hampton, 1994.)

Description	Species	Affecting fishery		Affected fishery		Class
		Area	Gear	Area	Gear	
Large-scale interaction between PS and PL fisheries	SJ	WCPO	PS	WCPO	PL	A or C
Interaction between DWFN surface fisheries and locally-based commercial surface fisheries	SJ, YF	WCPO	PS, PL	ID	PS, PL	C
	SJ, YF	WCPO	PS, PL	PH	Various	C
	SJ	WCPO/PU	PS, PL	PU	PL	A, C
	SJ, YF	WCPO/SB	PS, PL	SB	PS, PL	A, C
	SJ	WCPO/KI	PS, PL	KI	PL	A, C
	SJ	WCPO	PS, PL	FJ	PL	C
	SJ	WCPO	PS, PL	PF	PL	C
Interaction between industrial fisheries and artisanal/ subsistence fisheries	SJ, YF, BE	WCPO	PS, PL, LL	All Pac. Is. & SE Asian countries	Various	A, C
	SJ, YF	SB	PS, PL	SB	TR, HL	A, C
	SJ	KI	PL	KI	PL, TR, HL	A
	SJ, YF	ID	PL, PS	ID	TR, HL	A, C
	SJ, YF	PH	PS	PH	Various	A, C
Interaction between DWFN fisheries in different EEZs	SJ, YF, BE, AL	EEZs in WCPO	PS, PL, LL	EEZs in WCPO	PS, PL, LL	C
Interaction between different fleets in Solomon Islands	SJ, YF	SB (non-archipelagic)	PS (Co. #1)	SB (non-archipelagic)	PS (Co. #2)	A
	SJ	SB (archi-pelagic)	PL (Co. #1)	SB (archi-pelagic)	PL (Co. #2)	A
	SJ	SB (non-archipelagic)	PS	SB (archi-pelagic)	PL	A or C
Interaction between DWFN PS fishery and locally based "fresh-sashimi" LL fisheries	YF, BE	WCPO/PU	PS	PU	LL	B, C
		WCPO/FM	PS	FM	LL	B, C
		WCPO/MI	PS	MI	LL	B, C
		WCPO	PS	GU	LL	B, C
		WCPO/NC	PS	NC	LL	B, C
		WCPO	PS	FJ	LL	B, C
		WCPO/AU	PS	AU	LL	B, C
Interaction between DWFN PS fishery and "frozen-sashimi" LL fishery	YF, BE	WCPO	PS	WCPO	LL	B, C
Interaction between DWFN "frozen-sashimi" LL and locally-based "fresh-sashimi" fisheries	YF, BE	WCPO/PU	LL	PU	LL	A,C
		WCPO/FM	LL	FM	LL	A,C
		WCPO/MI	LL	MI	LL	A,C
		WCPO	LL	GU	LL	C
		WCPO	LL	NC	LL	C
		WCPO/FJ	LL	FJ	LL	A,C
		WCPO/AU	LL	AU	LL	A,C
Interaction between albacore driftnet and troll fisheries	AL	STCZ, Tasman Sea	DN	STCZ, NZ	TR	A, C
Interaction between surface and longline fisheries for albacore	AL	STCZ, Tasman Sea	DN, TR	South Pacific	LL	B, C

Gear codes: PS: purse seine, PL: pole-and-line, LL: longline, DN: driftnet, TR: troll, HL: handline

Country/area codes: AU: Australia, FM: Federated States of Micronesia, FJ: Fiji, PF: French Polynesia, GU: Guam, ID: Indonesia, KI: Kiribati, MI: Marshall Islands, NC: New Caledonia, NZ: New Zealand, PU: Palau, PH: Philippines, SB: Solomon Islands, WCPO: western Pacific Ocean, STCZ: sub-tropical convergence zone

Species codes: AL: albacore, BE: bigeye, SJ: skipjack, YF: yellowfin

Large scale tag-recapture experiments were carried out in the CWP by the South Pacific Commission (SPC) during two periods, 1977-80 and 1989-92. The experiment in the first period targeted skipjack tuna and the second, yellowfin tuna. Results largely from the second experiment were used by the SPC to investigate longline-purse seine fisheries interaction.

Returns from 181 large (>100 cm FL) yellowfin tuna during 1991-93 were used to test the null hypothesis that the relative probabilities of capture of the tagged yellowfin tuna by purse seine and longline gears are determined only by the relative catches by these gears. The null hypothesis would be accepted if yellowfin tuna were equally available to both gears, and rejected if unequally available to the gears. Overall, approximately 160 purse seine returns and 21 longline returns would be expected under the null hypothesis. Statistical tests showed that the observed number of longline returns (4 out of 181) was significantly less than that expected under the null hypothesis. Low reporting rates of longline-caught tagged fish, low returns, lack of thorough mixing of tagged fish, and reduced availability of tagged yellowfin tuna to longline gear are potential reasons for the lower than expected longline returns. Also, the expected longline returns may be artificially overestimated because they are based on ratio of catches, which are probably incomplete, especially for Korean and Taiwan purse seine catches. The tagging results, therefore, demonstrated surface to deep movement of yellowfin tuna, but so far not at a high rate to demonstrate a significant longline-purse seine fisheries interaction.

A unique tagging study has been proposed to determine whether this lower return rate from longlines is related to the source of the tagged fish; that is, tagged recoveries are principally surface-caught and tagged fish. The assumption is that there is vertical homogeneity and surface-caught fish move freely into the longline-vulnerable group. The proposed study is to tag a large number of longline-caught yellowfin tuna and evaluate the return rates of these releases by surface-gear and longline recaptures.

Size-frequency information was used in one study that investigated the extent of interactions between longline and purse seine fisheries. The study examined the size-frequency distribution of yellowfin tuna caught by the longline fishery in two different areas of the western Pacific in which there were relatively high and low purse seine fishing intensities. In areas with a history of high purse seine fishing intensity, there was a shift in the distribution with time towards a higher proportion of small yellowfin tuna in the longline catch with increase in purse seining intensity. In areas of low purse seine fishing intensity, no change in the size distribution was found with time. These results suggest a longline-purse seine fisheries interaction, but an alternative explanation could be that the dynamics of the yellowfin tuna population is more complex than assumed. For example, mixing of yellowfin tuna spatially throughout the central-western Pacific might occur slowly and not completely, the population might be significantly larger and more productive than generally assumed from experience with yellowfin tuna stocks in other regions, or the two fisheries might be exploiting separate stocks even in common fishing areas (Suzuki, 1994; WPYRG, 1994b).

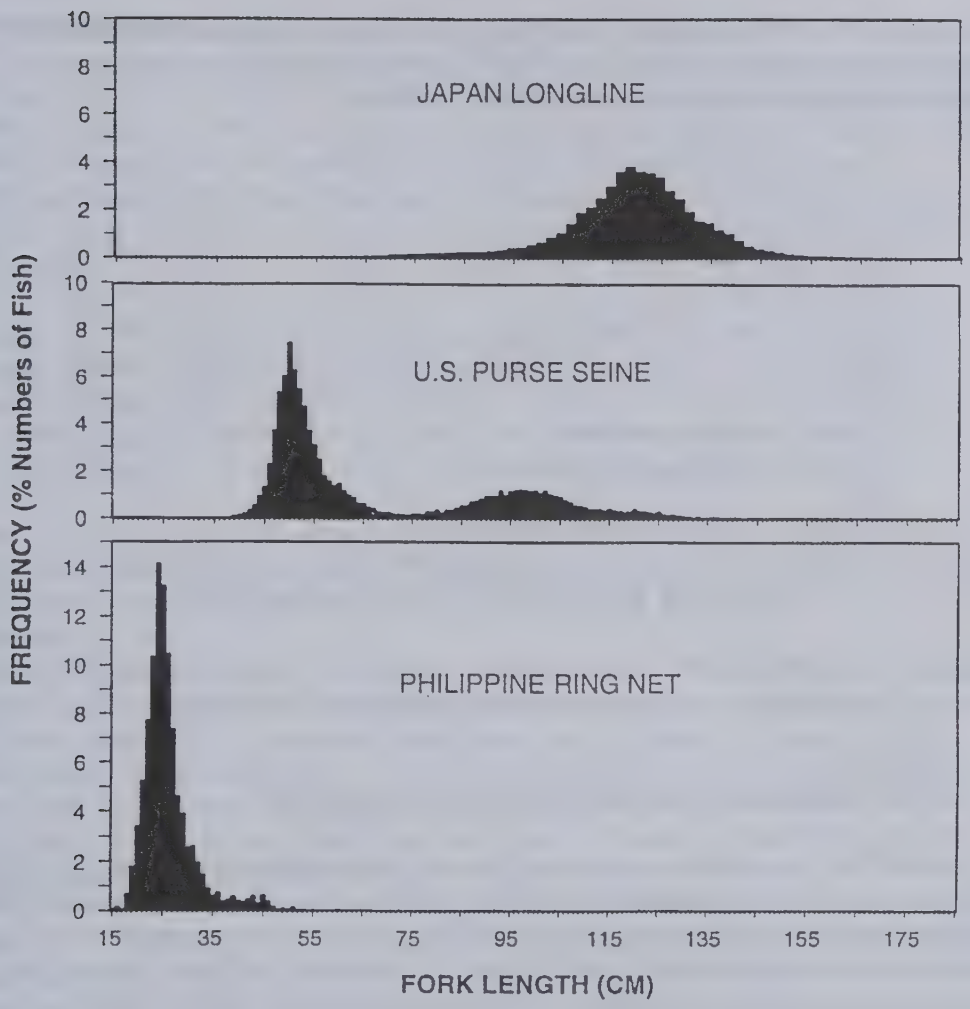

Figure 2. Length-frequency distribution of yellowfin tuna caught by different gears in the central-western Pacific Ocean.

Another study now underway using biological information may shed some light on the longline-purse seine interaction. It is a large-scale study on the reproductive biology of yellowfin tuna. The study is designed to use sex ratio, reproductive condition, spawning time and location, and other ecological information to determine the relationship of yellowfin tuna caught by purse seine and longline gears in similar areas and periods. Progress with this study so far has been made in collection of samples and in standardizing the technique for histological analysis of gonads. Final results are anticipated within two years.

The findings of the WPYRG fisheries interaction studies have been mixed, with evidence tending towards a weak or little interaction between the longline and purse seine fisheries in the CWP as a whole. This conclusion is further supported by evidence on exploitation rate of the yellowfin tuna population, which is currently low, averaging 0.20.

On the other hand, some localities in the region are experiencing substantially higher exploitation rates than this average, resulting in local depletion and possibly significant fisheries interactions at the local level (WPYRG, 1994b).

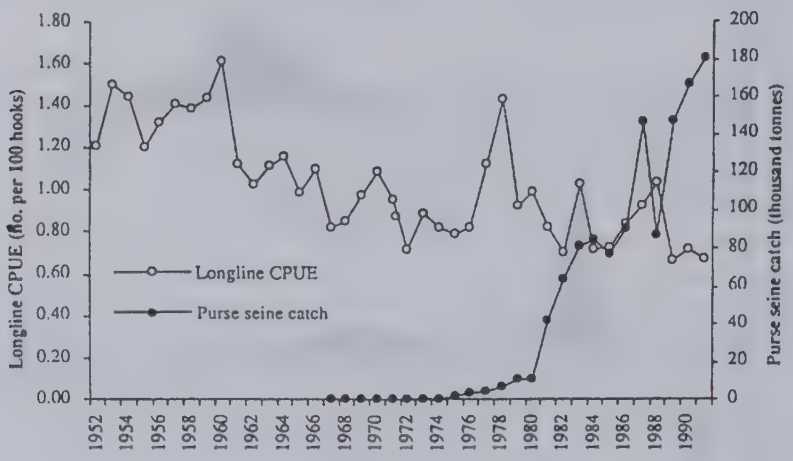

Figure 3. Yellowfin tuna CPUE for the Japanese longline fishery and yellowfin tuna catch for the purse seine fishery in the central-western Pacific Ocean (from Hampton, 1994).

4. LOCAL DEPLETION AND FISHERIES INTERACTION

The WPYRG has gained experience and a better understanding of processes involved in yellowfin tuna fisheries interactions in the WCP region. It has substantially completed its task of addressing the region-wide issue of longline-purse seine fisheries interaction. In 1994, it identified local depletion and local fisheries interaction as the next priority for concentrated, cooperative investigation. This new challenge for the Group will be considerably more difficult to address than the region-wide issue, largely because local issues are more complex (e.g., Hampton et al., 1996) and the number of cases in the region is growing rapidly with developments and expansion of the fisheries. Furthermore, non-resource mediated factors, e.g., culture and economics, may be as important as the resource mediated factors in understanding fisheries interactions at the local level. The Group is preparing to address local interaction issues with its expertise in tuna resource and fisheries science. It has proposed several new research initiatives, such as tagging of longline-caught yellowfin tuna, development of an analytical model that includes spatial and size-structure information, as well as movement information and morphological studies of air bladder development related to deep swimming or surface swimming preference (WPYRG, 1994b). It has also called for parallel studies on non-resource mediated factors to be conducted, which should contribute to informed decisions for resolving local tuna fisheries interactions issues.

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KOREAN TUNA FISHERIES IN THE PACIFIC OCEAN AND INTERACTION BETWEEN FISHERIES

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ABSTRACT

This paper describes long-term trends of yellowfin CPUE estimated from Korean longline and purse seine catch of yellowfin tuna in the southwestern and central Pacific during 1982-93, together with recent Korean tuna fisheries in the Pacific Ocean. In the western tropical Pacific where operations of Korean longline and purse seine vessels overlapped, the yellowfin CPUE of Korean longliners remained relatively stable during a period when the purse seine catch rose dramatically from about 3,000 mt in 1986 to 67,000 mt in 1992. While these results suggest a lack of influence of purse seining on longline catches, it was noted that the impact of large catches of small yellowfin by the purse seine fishery may take time to show its effect on the yellowfin resource.

1. INTRODUCTION

The Korean distant water fishery began in 1957 in the Indian Ocean. Since then, Korean longline vessels have expanded operations into all of the world's oceans. For the Pacific tuna fishery which began some years later in mid-1960s, Korea had increased tuna longliners every year up to 270 vessels in 1974, followed by decrease in successive years to 94 vessels in 1985 and increased again thereafter (Gong et al., 1993). In addition to longliners, purse seiners started to operate exclusively in the southwestern Pacific since 1980. Compared to longliners, the size of the purse seine fleet is not large; during 1980-93 number of purse seiners averaged 20 each year.

The area that Korean tuna longliners and purse seiners operate overlap to some extent in the Pacific. This implies that certain types of interaction, as classified by Hampton (1994), between those two tuna fisheries on tuna species might occur. Tuna interaction studies certainly should be emphasized in order to promote effective management of tuna resources; however, these studies often require long-term efforts to secure sufficient information to analyse. In this sense, interaction studies for tuna species of world's oceans should be cooperative among tuna fishing countries for better results.

This paper describes long-term trends of yellowfin CPUE estimated from Korean longline and purse seine catch of yellowfin tuna in the southwestern and central Pacific during 1982-93, with a view to disclosing a possibility of interaction between the fisheries on yellowfin.

2. KOREAN TUNA FISHERIES IN THE PACIFIC

Catches by the Korean tuna vessels operating in the Pacific have increased year by year and exceeded 100,000 mt for the first time in 1987 (Park et al., 1990). The 1987 tuna fleet consisted of 138 longliners and 20 purse seiners. During 1990-92, the catch by the Korean tuna fleet amounted to over 200,000 mt annually (Tables 1 and 2); however, in 1993 the catch decreased significantly to about 160,000 mt. This decrease was largely attributed to the decrease in catch by purse seiners (Table 2) rather than the decrease in catch by longliners of relatively small fleet size compared to previous year. Currently about 150 longliners and 30 purse seiners are engaged in tuna fishing in the Pacific.

2.1 Longline Fishery

The number of Korean longliners operating in the Pacific ranged from 100 to 200 vessels during 1980s and up to the present (Park et al., 1990; Gong et al., 1993); the catch by the longline fleet also varied by year but did not correspond closely with the changes in effort. During 1990-93, the average number of longliners and catch were 179 vessels and 40,000 mt, respectively (Table 1). During this period the catch and number of vessels showed a decreasing trend.

Species composition of longline catch was 50% bigeye, 29% yellowfin and 21% other species, on average (Table 3). The CPUE of all species by longliners ranged from 1.3 to 1.8 fish/100 hooks during 1990-93; the CPUE decreased in 1993 by 19% compared to 1992 (Table 1). In recent years, fishing grounds for the longline fishery have become narrower by giving up albacore catch from the southern and northernmost part of Korea's usual fishing grounds in the Pacific (Figure 1). Fishing activities have been generally concentrated in the southwestern and central Pacific since 1989 (Gong et al., 1993).

2.2 Purse Seine Fishery

The Korean purse seine tuna fishery which targets mainly skipjack and yellowfin tunas recorded the highest total catch at 227,518 mt with 36 vessels in 1991, but showed decreasing trends thereafter (Table 2). Species composition of purse seine catch was 69% skipjack and 31% yellowfin tuna on average (Table 3). The CPUE for all species by purse seine fluctuated between 20 and 27 mt/haul in recent years; CPUE of yellowfin remained similar level for each year, whereas that of skipjack decreased from 20 mt/haul in 1991 to 13 mt/haul in 1993.

Fishing area by purse seine extended westward in recent years compared to late 1980s (Figure 2). In the late 1980s the range of purse seine fishing operation was between 138-166°E, while in 1990-93 it was between 135°E-175°W.

Table 1. Number of vessels, catch, and CPUE of Korean longline fishery in the Pacific Ocean during 1990-93.

Year	Vessels	Catch (mt)	CPUE (no. fish/100 hooks)				
			All	YFT	BET	ALB	OTH
1990	182	44,762	1.40	0.55	0.69	0.07	0.09
1991	220	38,751	1.32	0.40	0.71	0.11	0.10
1992	166	40,756	1.75	0.66	0.74	0.18	0.17
1993	148	36,459	1.41	0.48	0.67	0.09	0.17

All: all species, YFT: yellowfin, BET: bigeye, ALB: albacore, OTH: others

Table 2. Number of vessels, catch, and CPUE of Korean purse-seine fishery in the Pacific Ocean during 1990-93.

Year	Vessels	Catch (mt)	CPUE (mt/haul)			
			All	YFT	SKJ	OTH
1990	39	173,343	41.4	9.0	32.1	0.3
1991	36	227,518	27.4	7.5	19.8	0.1
1992	36	182,287	24.3	8.6	15.7	-
1993	34	126,648	20.4	7.8	12.6	-

All: all species, YFT: yellowfin, SKJ: skipjack, OTH: others

Table 3. Species composition of Korean longline and purse-seine catches during 1990-93.

Year	Longline Catch (%)			Purse Seine Catch (%)		
	BET	YFT	OTH	SKJ	YFT	OTH
1990	46.5	31.0	22.5	80.0	20.0	-
1991	52.5	27.5	20.0	75.6	24.4	-
1992	48.5	30.7	20.8	63.2	36.8	-
1993	54.5	27.4	18.1	58.4	41.6	-

BET: bigeye, YFT: yellowfin, SKJ: skipjack, OTH: others

3. INTERACTION BETWEEN KOREAN TUNA FISHERIES IN THE PACIFIC

Among the interaction types classified by Hampton (1994), the interaction between two different fishing gears on certain tuna species can be studied when catch and CPUE data are available. Tuna fisheries interaction study, therefore, may not obtain anticipated results without such sufficient information from each fishery involved.

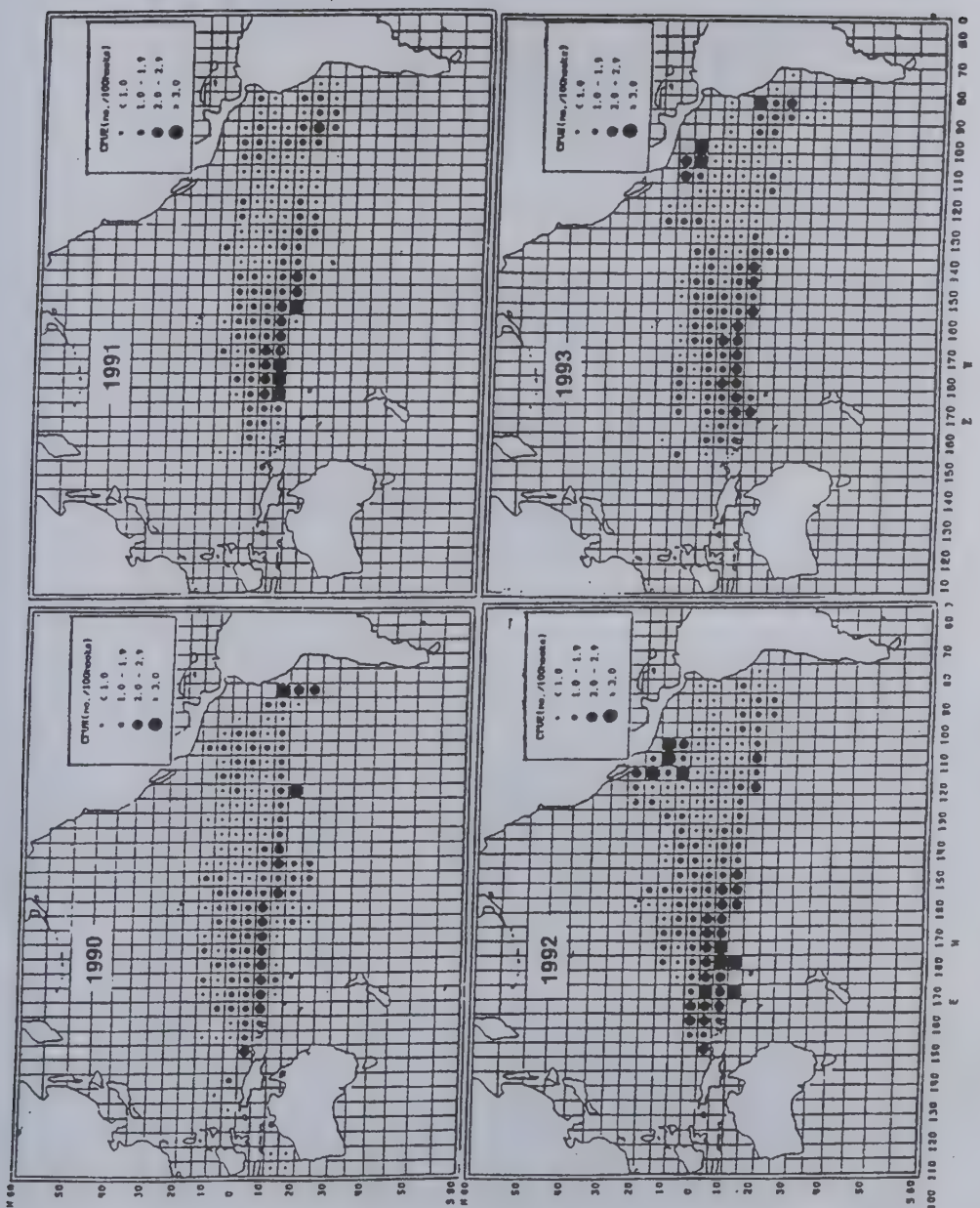

Figure 1. Korean longline fishery operation area and CPUE distribution of all species, 1990-93.

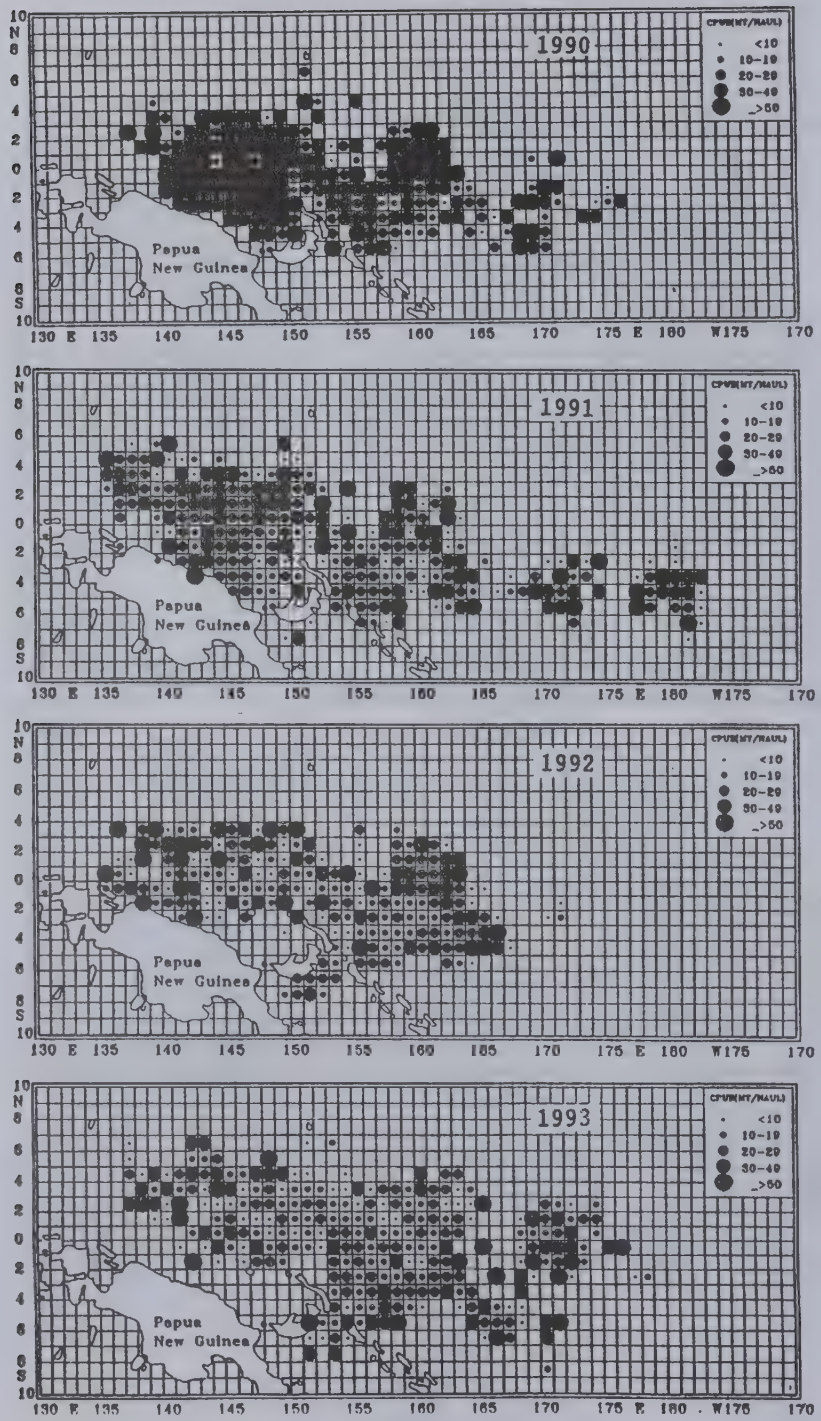

Figure 2. Korean purse seine fishery operation area and CPUE distribution of all species, 1990-93.

For interaction study, we reviewed changes in yellowfin CPUE by Korean longliners to see if it was affected by yellowfin catch by Korean purse seiners operated in the same area and same time. The shaded rectangle shown in Figure 3 between 140-180°E and between 10°N-10°S represents an area in which interactions between Korean longline and purse seine fisheries on yellowfin might have occurred.

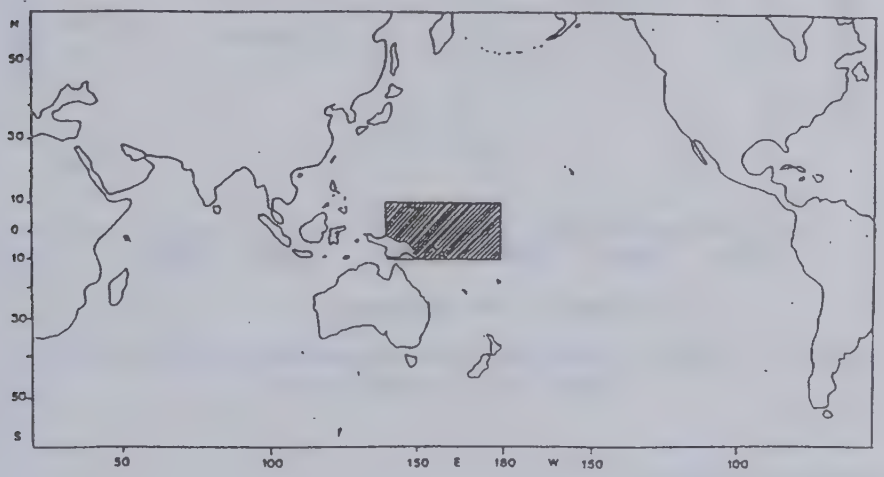

Figure 3. Interaction zone.

Yellowfin CPUE from longline fishery in this interaction zone during 1982-93 varies by year, ranging from 0.61 to 1.46, but as year progresses it becomes relatively stable (Figure 4). Even though wide range of changes was shown, yellowfin CPUE by Korean longliners in recent years appeared to be similar to that at the early phase of Korean purse seine fishery. The CPUE during the 1982-86 period when the purse seine catch amounted to nearly 1,000 to 3,000 mt was 0.92/100 hooks on an average, and that during 1987-93 when the purse seine catch increased dramatically up to about 67,000 mt was 0.91/100 hooks.

From these results, it was noted that there was no direct interaction between the purse seine catch and longline catch rates in the southwest Pacific and these results were consistent with those taken by Suzuki (1988). However, considering the purse seine catches are usually made of much smaller yellowfin, which will grow to be part of longline catches after some years depending on oceanographic conditions, the impact of large catches of small yellowfin by the purse seine fishery may take time to show its effect on the yellowfin resource (Hampton, 1994; Medley, 1994).

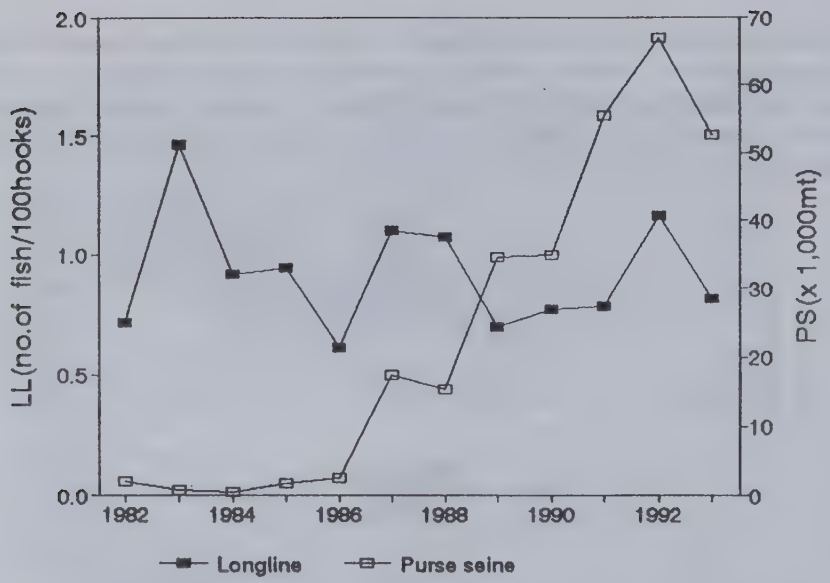

Figure 4. Changes in yellowfin tuna catch by purse seiners (open) and CPUE by longliners (closed) during 1982-93.

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A SPATIAL MODEL TO INVESTIGATE THE EFFECTS ON CATCHES OF TUNAS IN THE EASTERN PACIFIC OCEAN WHICH MIGHT HAVE ENSUED FROM CURTAILMENT OF CERTAIN FISHING METHODS

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ABSTRACT

Boats of various types from several nations exploit tunas in surface waters of the eastern Pacific Ocean using different modes of operation. There is some concern regarding two of these modes. One involves taking tunas associated with dolphins, and in the other tunas are taken while associated with passive floating objects, or "logs." In both cases there is concern for non-target species, and in one there is additional concern that the fishery might be harmed because smaller individual fish tend to be taken. A spatial model has been developed to simulate the fishery. The catches from the model are compared to those from the fishery, and then to those simulated with moratoria on the modes of concern.

Two species of tunas, yellowfin (*Thunnus albacares*) and skipjack (*Katsuwonus pelamis*), are considered. The results of this study tend to confirm an earlier, simpler, study on the effect of ceasing to use dolphins in catching tunas. It appears the yield of yellowfin would increase immediately if log fishing ceased, whereas a temporary decline was expected before gaining an increased yield per recruit. The discrepancy is a result of an interaction between the fishing method and the mixed-species nature of the fishery.

The effects of fishing mode are not universal, but interact with the type and nationality of the vessels. Vessels were divided into categories based on their type and nationality, and the catches of each category were tabulated. Moratoria improve the catches of some categories of vessel while causing a decline for others. The effects of such moratoria changed quite markedly for some categories within the period of the simulation.

1. INTRODUCTION

Purse seiners seeking tunas in the eastern Pacific Ocean operate in three basic modes which are commonly termed log fishing, dolphin fishing and school fishing. Schools of tuna are the target in each case and the first two terms refer to fishing directed at schools that are associated with floating objects, or "logs," and dolphins. The fishery is prosecuted by an international fleet with boats of various sizes and levels of sophistication which are capable of different fishing modes. Log and school fishing are options available to every boat, but dolphin fishing requires additional gear which makes it impractical for some of the smaller boats. The different fishing modes exert different size selectivities on the fish. The purpose of this study is to consider the effects on catches of ceasing to use one or more of these fishing modes. Some categories of vessel may gain while others lose, so these

effects will also be considered by vessel size, type and national flag. Thus, this is a study of how the relative success of different groups of vessels interacts with the fishing methods that are open to them.

The fishing methods will be explained briefly, and then the reasons why vessels might switch among fishing modes will be discussed, before explaining how such changes might affect the different categories of vessels.

Schools of tunas frequently associate with floating objects (Greenblatt, 1979). Boats fishing these logs will drift alongside them, using sonar to monitor the fish associated with them. The association of the school to the log is rather loose, and varies throughout the day. There may be more than one school associated with the log, and the boat may set its net more than once on the same log. The yellowfin (*Thunnus albacares*) caught in this manner tend to be smaller than those caught using the other two modes, and more skipjack (*Katsuwonus pelamis*) tend to be taken in log fishing than in the other modes (IATTC, 1994: Table 30). A single set close to, or around, a log will often yield a mixture of yellowfin and skipjack; non-target species are also frequently caught.

Yellowfin also associate with dolphins (Perrin, 1969); skipjack do so only very rarely. Boats described as dolphin fishing search for dolphins which are more readily seen because they regularly break the surface. Each dolphin school is investigated: if there are sufficient yellowfin, then the net is set around the joint aggregation, and the dolphin are released before the tuna are removed. These yellowfin tend to be larger than those caught using other methods.

School fish are not associated with either dolphins or logs. They can be sighted visually as a dark patch in the water, or as disturbance caused by them swimming close to the surface (Scott, 1969). Both yellowfin and skipjack are taken in this manner, as joint aggregations and as pure schools. The yellowfin tend to be of an intermediate size, between that of those caught on logs and those caught with dolphins.

Boats catching the younger, smaller fish are likely to have an effect on those catching older, larger fish. This effect will not be reciprocated if it is assumed that recruitment is density independent at the population sizes considered (IATTC, 1994: Figure 59).

Size limits are used to manage some fisheries. If recruitment is independent of spawning stock and the size limits succeed in increasing the mean yield per recruit, then size limits can increase the long-term yield of a stock. Size limits would not increase the current mean yield per recruit of skipjack (IATCC, 1994: 80-82). For yellowfin, a size limit might be desirable, but would not be practical because there is usually considerable range in the size of fish taken from a single school. If boats ceased to fish logs, the mean size of the overall catch would be increased, so a switch from log fishing to the alternative modes of fishing might be a reasonable proxy for a minimum size limit.

Dolphins are sometimes killed when fishing for tunas associated with them, despite the precautions which are taken to try to avoid dolphin mortality. As a result, dolphin fishing is not permitted for vessels registered in some nations, and many consumers refuse to purchase tuna caught in this manner Joseph (1994). If either of these decisions reduces the

effort directed to dolphin fishing, then that effort is likely to be redirected to log and school fishing. This will affect the size structure of the population and the catches made by vessels currently using other methods.

In redistributing the effort from one mode to another, Anganuzzi (1996) considers each category of class and national flag separately. Nationality was included in the stratification of vessels because vessels of the same size and nationality are likely to operate under similar restraints. Boats of some class-flag combinations fish only near their home ports. Nations may negotiate licenses to fish the Exclusive Economic Zones (EEZ's) of other countries. Boats of such nations, and those of their hosts, will have access to waters that are unavailable to vessels flying other flags.

By using Anganuzzi's (1996) program, simulations are performed to estimate what would have happened to the catches of 1980-86 if dolphin fishing, log fishing, or both modes of fishing had been foregone. The displaced effort would have interacted with the effort already expended on the alternative fishing modes; these interactions are the focus of this study. It is expected that some categories of vessels will gain and others will lose from such changes, but the system is sufficiently complicated that no clear prediction can be made without a quantitative study. The overall effect of these changes is, of course, the sum of the changes that would be experienced by each category.

The period 1980-86 (inclusive) was chosen for the study. The number of sets on logs nearly equalled the number made on dolphins in the first half of the period, but log sets were relatively rare in the second half (IATTC; 1994: Table 3c). Each half was considered independently to see how the gains and losses varied with this extrinsic factor.

2. METHODS

Two species were considered, yellowfin and skipjack, within the simulation procedure. The aim was first to develop a model that was able to mimic catches of each species over the period considered. Then that model was used to predict what the catches would have been during that period if the fishery had operated under additional constraints.

Yellowfin were modelled using as a starting point the 2½° area-month model fitted to the data from years 1980-86 described by Mullen (1996). Yellowfin are recruited, they move around within the geographical constraints of the model, and suffer both natural and fishing mortality. Effort is a measured variable that is assigned to one of the three modes of fishing, each of which has a different age-specific catchability coefficient, which also varies by month and area. Movement is characterized by a field of diffusion coefficients which was estimated by Mullen (1996).

Recruitment is not knife-edge, and seems asynchronous. Representatives of a cohort are first caught in only a few cells, but may be found over a relatively large area shortly afterwards (Punsly and Deriso, 1991). Mullen (1996) deemed it unreasonable to assume the entire population was concentrated in those few cells and then dispersed extremely rapidly. It was assumed instead that the fish initially become vulnerable to capture within only a small portion of the area within which they are present. A few months after a cohort first appears in the catch, representatives are taken from a large zone within the

region. From there, fields of diffusion coefficients could describe them as moving offshore and dispersing gradually to cover the entire region modelled in a manner consistent with the appearance of the cohort in the catch. Two cohorts are modelled per year, one first appearing around May, and the other in November. The fish are estimated to be approximately 6 months old at these times. The recruits that first appear in May are deemed fully recruited a year later, while those first appearing in November achieve this by the following September. The estimates of movement of the young fish are not reliable before these dates. Significant catches are made before these dates, however, particularly by log fishing.

Catches of yellowfin are described by the following equation:

$$C_{t,c} = \sum_{i,j,s} q_{i,j,s,t,c} \, E_{i,j,s,t,c} \, A_{i,j,t} \, \frac{(1-e^{-Z_{i,j,t}})}{Z_{i,j,t}}$$

$$\text{where } Z_{i,j,t} = M\delta t + \sum_{s} q_{i,j,s,t,c} \, E_{i,j,s,t,c}$$

where C is the catch at time t by vessels of category c, defined by flag and t,c vessel characteristics; q is the catchability coefficient: M is the instantaneous natural mortality rate; i and j are the latitude and longitude of the 2½° areas; s is the fishing mode (1-3); E is the effort in boat days; and δt is the time increment - one "week," or a fifth of a month. An annual rate of 0.8 was assumed for M; q was obtained from the work of Punsly and Deriso (1991), briefly described by Mullen (1996). Monthly effort was available from compilations of logbook records made by the IATTC; these values were divided by five to give weekly values. The catchability coefficients were in general, specific to the particular areas and months, but one run was made in which the mean value over the seven years was used as the catchability for a given cohort, area and month.

Punsly and Deriso (1991) took from cohort analysis estimates of numbers of each cohort from recruitment until they no longer appeared in the catches. The cohort analysis had been made on spatially aggregated data. They assessed the distribution of the cohorts using spatial catch statistics, employing a general linear model to take into account factors such as the power of each particular vessel and the skill of individual captains. Then, with the local abundance determined, they divided the total catch attributed to each set in each time-area stratum by the days of effort devoted to that mode of fishing. This gave the catchability coefficients, q, above. Mullen (1996) took those distributions of numbers of fish from Punsly and Deriso (1991), estimated diffusion parameters, then revised the estimates of distributions. Here, the original recruitment figures are used: those recruits then suffer time, area, and age specific mortality, Z. For 10 to 12 months, depending upon cohort as explained previously, the sum total of each of these cohorts is redistributed at the end of each month to match the distribution estimated by Punsly and Deriso (1991). The larger, fully recruited, cohorts move according to the weekly diffusion coefficients estimated by Mullen (1996)

Skipjack were modelled very simply. Analysis of yield per recruit suggests they are under-exploited within the region considered and that the yield would increase with effort even if the effort increased to two or three times current values (IATTC, 1994: 80-82). In the simulation catch per unit of effort was assumed constant through time for each area-fishing-mode stratum. For each month, the mean of the values for that month over the 7 year series was used. It was assumed that the skipjack were always available and vulnerable to capture, but were not sought when yellowfin were also vulnerable. The catch rate, however, was limited to the mean over the region for each fishing mode, because some large values were calculated for small amounts of effort. Those values might have biased the redistribution of effort and led to an overestimate of the catch when the effort allocation program was used.

Initially, the monthly effort expended in the 2½° areas of the model by vessels of each category using the three modes of fishing was obtained from the IATTC data base. For the next stage, an effort allocation program (Anganuzzi, 1996) was used to redistribute geographically the effort recorded in the data base. Finally, the effects of different fishing methods were investigated by simulating what the effects might have been had certain modes of fishing ceased. It was assumed that if this happened, then the effort which had been expended on one mode would be redirected to others. The effects of a cessation of dolphin fishing and log fishing were considered, both separately and combined. This was done by setting the catchability coefficient of the particular fishing method or methods to zero and reassigning the effort using Anganuzzi's (1996) program.

3. RESULTS

The model for yellowfin is the more complex and readily testable. It is considered first, then various scenarios are considered by looking at the predicted catches of yellowfin and skipjack combined for the entire international fleet. Having considered the global effect of changes in the behaviour of fishermen, we shall then look for interactions within the international fleet to see whether individual categories of vessels might have fared better or worse than average.

Figures 1A and 1B compare the recorded catches of yellowfin to those predicted given the estimated abundance obtained from the movement model. For Figure 1A, monthly area-specific catchability coefficients were used; while for Figure 1B, the mean value for that month and area calculated over seven years was used for each year. The sum of squares of the differences between catches and those predicted in Figure 1A, is about one half that of Figure 1B. The specific values of catchability clearly give a better approximation to the observed data than the mean values, as would be expected. The worst deviations in Figure 1A occur in 1980 and 1985, when the predicted catches are significantly less than those recorded. This may be due to the inability of the movement model to transport enough fish into the areas being fished at those times.

All subsequent runs of the model used the catchability coefficients that were used in the production of Figure 1A. The next stage was to compare the predicted catches using the effort distribution as determined by Anganuzzi's effort allocation program. This comparison is available in Figure 2 for yellowfin (Figure 2A) and for yellowfin and skipjack combined (Figure 2B). The solid lines of Figure 2 represent the catches predicted

using the effort allocation program (Anganuzzi, 1996). Thus, the model predicts a similar time-series of catches when using Anganuzzi's (1996) program for allocating effort as it does when using the recorded distribution. The series predicted using the effort allocation program will henceforth be used as a standard of comparison when investigating the effects of curtailing the fishery.

The questions to be answered are: what would have happened if none of the vessels that comprise the international fleet had operated in the dolphin fishing mode; if no log fishing occurred; or if fishing involved only the school-fishing mode? These scenarios are easily set by fixing the catchability coefficient for any given mode(s) of fishing at zero. The predictions of the catches of yellowfin for these three scenarios are given in Figures 3A-5A with the predictions given by the effort allocation for unrestricted fishing. Figures 3B-5B show equivalent predictions for the sum of yellowfin and skipjack.

Finally the effects of the three postulated scenarios were compared for twelve categories of vessel: four groups of nations and three classes of vessels. The data for 1980-86 were partitioned into two segments, 1980-83 and 1984-86. Catches of yellowfin alone and of yellowfin and skipjack combined were calculated. Each scenario is compared by dividing the catch for that scenario with that predicted by the model using the effort allocation program. The results are presented in Table 1. Some of the categories defined were empty: that is there was no boat of a particular class and national group operating within that segment of the period. In other cases, the total catch predicted using all three modes of fishing was less than 5,000 tons for each segment. These cases are denoted with an asterisk: the predictions are based on so few data that they should be viewed with much scepticism.

4. DISCUSSION

Fish catches are so inherently variable that predicting catches given proposed or possible changes in the behaviour of fishermen is fraught with difficulty. Those changes could easily be swamped by other unanticipated changes, many of which will be outside human control. This problem is sidestepped by taking a past period and predicting what would have happened if the behaviour had been changed for that period. The model that has been considered is less than perfect for reasons that will be discussed. Even if it were perfect for the period modelled, future changes in external factors would render it only a rough guide to the future. But most fisheries models are only rough guides because they too are subject to externalities. By predicting what might have happened, we hope to show the general scope of effects which can be anticipated, without creating illusory precision or calculating spurious confidence limits.

In considering the sensitivity of our results to parameters, we do not consider the parameters individually. An overestimation of recruitment will not occur in isolation, for instance, but will be associated with persistent overestimation of the abundance of that cohort and underestimation of all its catchability coefficients. With such errors, our simulation would overestimate the resilience of the cohort to fishing pressure. If the errors are pandemic, then the movement model should not present a problem because the same

Table 1. Predicted effects of cessation of particular modes of fishing on catches made by vessels of 12 categories (A-L) during two segments of the period studied (1980-83 and 1984-86), expressed as proportions of the catches expected when all three modes of fishing are used. The categories denoted with asterisks represent cases for which the total predicted catch with all three modes of fishing was less than 5,000 tons for both segments. The vessel categories are not identified to preserve the confidentiality of information provided by the vessel owners and captains.

YELLOWFIN

	No dolphin fishing		No log fishing		No dolphin or log fishing	
	80-83	84-86	80-83	84-86	80-83	84-86
Category						
A*	0.9397	0.8047	1.1623	0.6002	1.0933	0.5607
B	0.9791	1.0228	1.1703	1.0335	1.2110	1.1255
C	0.8654	0.8142	1.2051	1.0305	1.2018	0.8815
D	0.8935	0.8071	1.4581	0.9730	0.8426	0.7393
E	0.8486	0.9047	0.9726	1.1887	0.6676	0.7617
F*	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
G*	0.8854	0.0000	2.8542	0.0000	3.6875	0.0000
H*	0.5517	0.0000	0.4064	0.0000	0.3473	0.0000
I	0.7268	0.5891	1.0736	0.9673	0.8423	0.9103
J	0.9257	0.9239	1.2091	1.0601	1.1239	0.9951
K	0.8147	0.7577	1.0494	1.0560	0.8287	0.8482
L	0.8417	0.7684	0.9777	1.0180	0.6722	0.7559
All Combined	0.8563	0.7982	1.0610	1.0250	0.8451	0.8340

YELLOWFIN + SKIPJACK

	No dolphin fishing		No log fishing		No dolphin or log fishing	
	80-83	84-86	80-83	84-86	80-83	84-86
A*	0.9585	0.8445	0.9666	0.5513	0.9197	0.5383
B	0.9969	1.0435	1.1017	1.0262	1.1443	1.1297
C	0.9766	0.9265	1.0241	1.0265	1.0601	0.9704
D	0.9766	0.9258	1.0201	0.9423	0.9059	0.8688
E	0.9802	0.9860	0.8959	0.9996	1.0076	0.9541
F*	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
G*	0.9688	0.0000	1.1042	0.0000	1.4514	0.0000
H*	0.7032	0.0000	0.5583	0.0000	0.5671	0.0000
I	0.9446	0.7136	0.8882	0.9531	0.8646	1.0058
J	0.9463	0.9363	1.0191	1.0070	0.9805	0.9560
K	1.0485	0.7904	0.8626	1.0268	0.8266	0.8281
L	1.1180	0.9873	0.6870	0.9330	0.6613	0.8585
All Combined	1.0593	0.9496	0.8212	0.9717	0.8056	0.9150

proportion of the population will move at each time step. Errors will, however, be introduced into the movement model whenever the estimated distribution of the population is incorrect. There are so many diffusion parameters that none will have a large effect on the overall simulation. The spatial pattern of diffusion is much more important in determining the distribution of fish. If the diffusion pattern increases the aggregation of fish in the model, then this will make the model more sensitive to the fishery and accentuate the results presented.

Within the seven years considered, catchabilities fluctuate such that different methods of fishing become more or less attractive. That is why Table 1 allows comparison of the different scenarios for two intervals: 1980-83, when there was much log fishing, and 1984-86, when there was little.

It would be a mistake to assume that the precision suggested by Figure 1A, comparing the model output to observed catches, will apply to the hypothetical scenarios. The model is tightly constrained by the catchability coefficients, which were estimated from the observed catch rates. Catchability coefficients are available for yellowfin for a given area-month stratum only when there was effort in that stratum; otherwise, their default value is zero. As a result, effort is always confined within that zone in which it was originally recorded. The modelled effort is likely to be redistributed and may withdraw to a smaller zone, but it will not expand into areas that were not originally exploited during that particular month.

The caveats issued by Anganuzzi (1996) apply, of course, to these results which depend on his program: effort is modelled continuously rather than as discrete boats following a particular strategy in trading-off risk against expectation. Economics are assumed constant, whereas, in reality, they vary greatly. Log fishing conserves fuel, so the proportion of effort expended upon this mode will depend to some extent on the cost of diesel.

Having estimated the age, position, and time dependent movement parameters for the population over the period 1980-86, it is assumed that these parameters would not change with the behaviour of fishermen. In arguing that movement could be parameterized with variable diffusion coefficients, Mullen (1989) suggested that it is likely these parameters would be a function of local population density, which is affected by the fishermen. Unfortunately, the diffusion coefficients might not be related directly to the population density because they may also depend on the local environment. The arguments of Mullen (1989) suggest, however, that the diffusion coefficients are likely to be positively correlated with population density when considered by area-time stratum across model runs. Without further information, the parameters were not corrected for this postulated effect.

No account has been made for the fact that catches might be limited by the number of dolphins or logs. If either dolphin fishing or log fishing is foregone, the number of fish rendered unavailable by their association with dolphins or logs is likely to increase. The effort which had been expended on that mode of fishing will be redirected. Thus, if

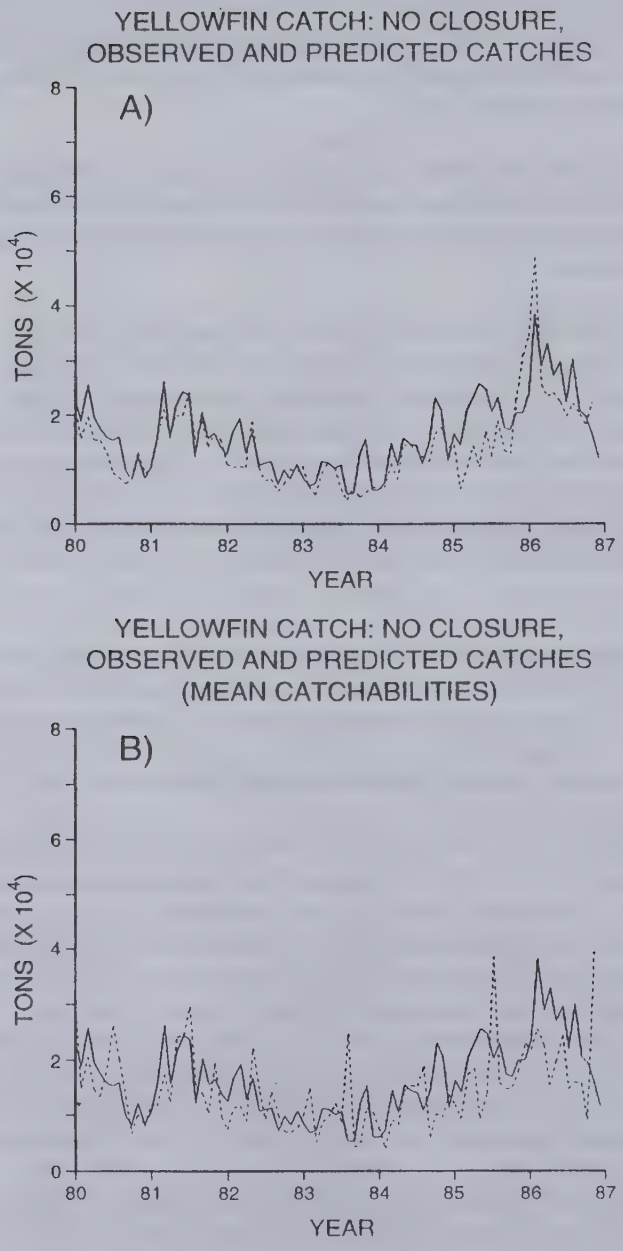

Figure 1. Observed catches (solid line; total catch = 1,337,266 tons) compared to those calculated from the recorded distribution of effort (dotted lines), using A) monthly values of catchability (total catch = 1,178,956 tons) and B) monthly mean values of catchability (total catch = 1,222,957 tons).

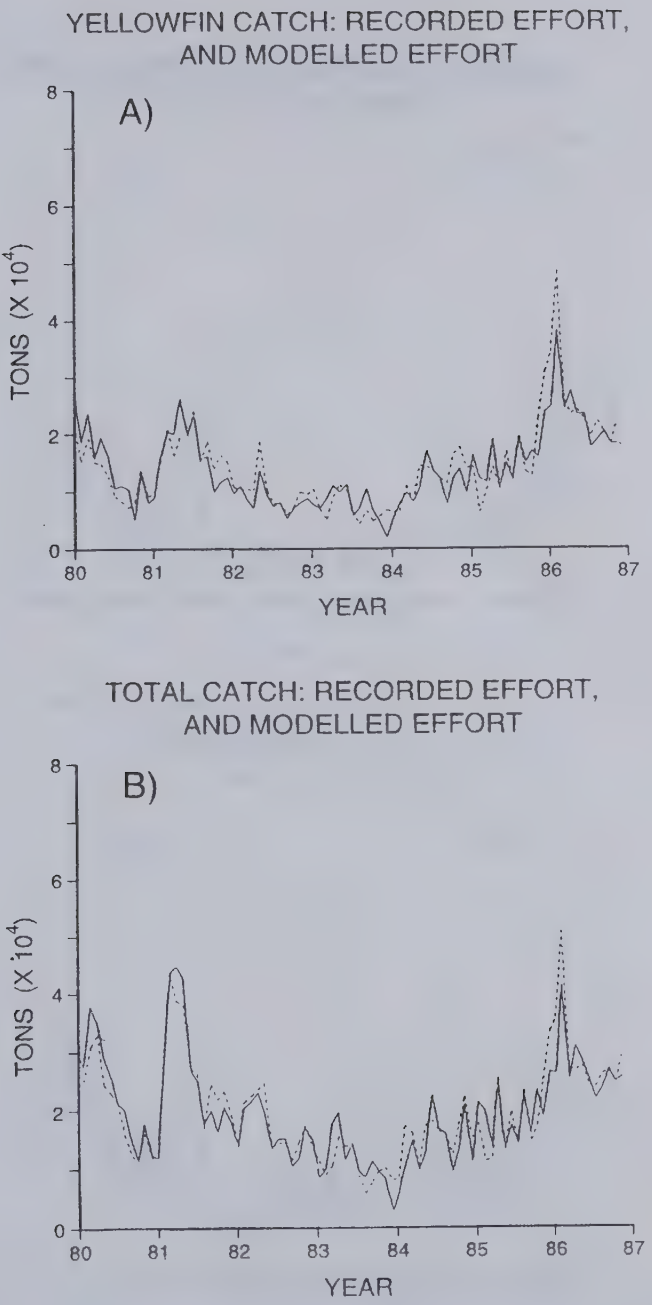

Figure 2. Predicted catches for the recorded effort distributed by Anganuzzi's allocation model (solid lines) compared to those calculated for the recorded distribution of effort (dotted lines) for A) yellowfin and B) yellowfin + skipjack. The predicted total yellowfin caught over the period with modelled effort was 1,151,238 tons; versus 1,178,956 tons calculated given the recorded distribution of effort. For yellowfin and skipjack combined, the totals were 1,636,232 tons for the modelled effort and 1,653,834 tons for the recorded distributions. The predictions using modelled effort, the solid lines of this figure, also appear in Figures 3-5.

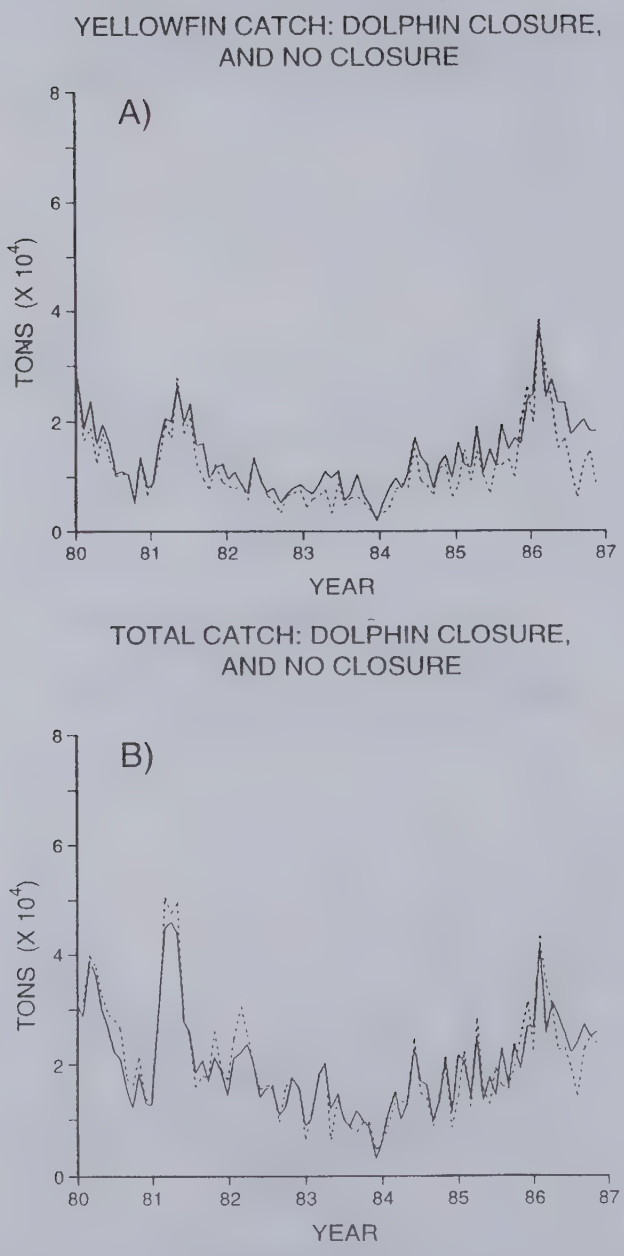

Figure 3. Predicted catches for distribution of effort allocated using all modes of fishing (solid lines) compared to those with no dolphin fishing (dotted lines) for A) yellowfin (total without dolphin fishing, 952,492 tons) and B) yellowfin + skipjack (total with no dolphin fishing, 1,656,560 tons).

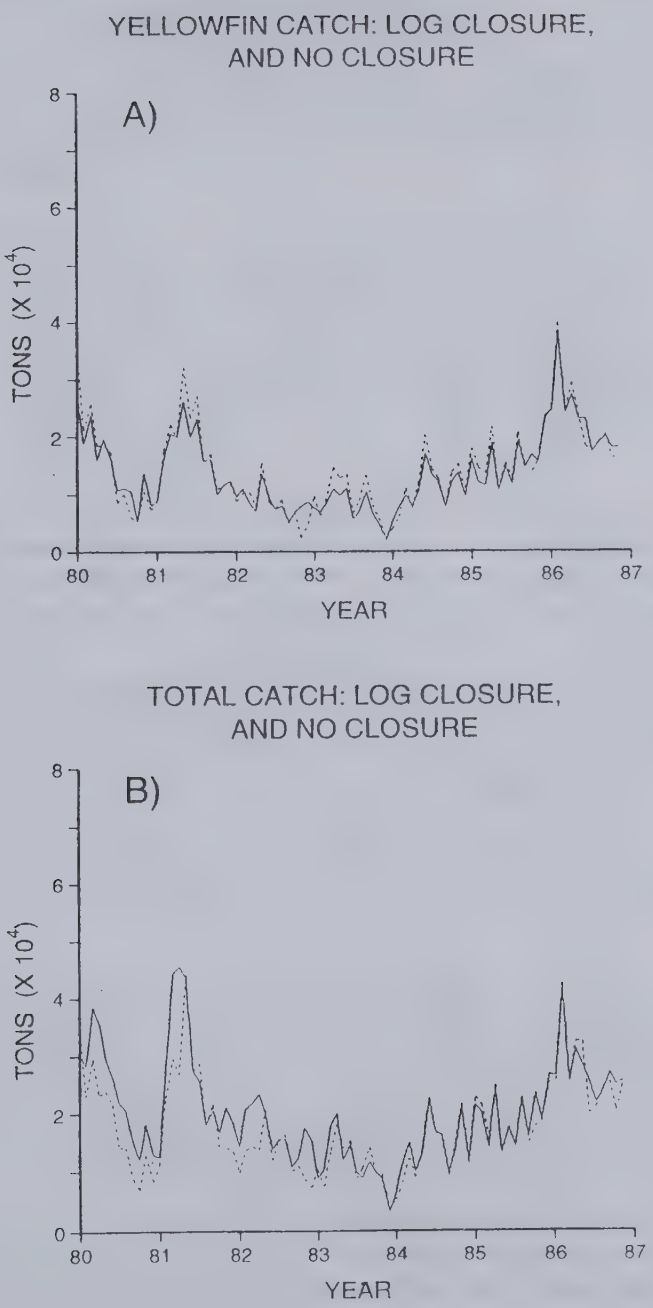

Figure 4. Predicted catches for distribution of effort using all allocated modes of fishing (solid lines) compared to those with no log fishing (dotted lines) for A) yellowfin (total with no log fishing, 1,200,861 tons) and B) yellowfin + skipjack (total with no log fishing 1,448,911 tons).

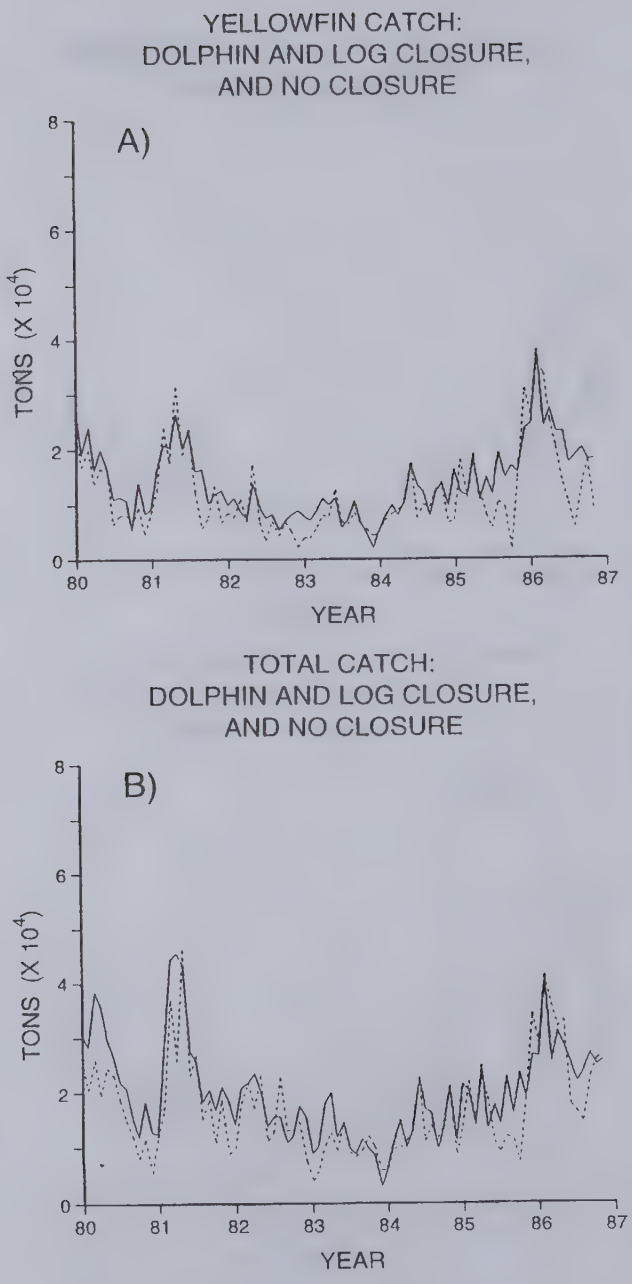

Figure 5. Predicted catches for distribution of effort allocated using all modes of fishing (solid lines) compared to those predicted using effort with no dolphin or log fishing (dotted lines) for A) yellowfin (total with no log or dolphin fishing: 966,537 tons) and B) yellowfin + skipjack (total with no log or dolphin fishing: 1,394,675 tons).

dolphin fishing ceases, then logs will be fished more intensively; and vice versa. A log which is being fished by one boat is not available to another, so it might take more time to find a suitable log when there are more boats log fishing. The same is true if boats are looking for dolphins; a school of dolphins is likely to yield few fish immediately after it has been fished. More boats fishing dolphins will reduce the mean time between any school being fished, giving it less time to recover, or "recruit," more tunas. These saturation effects are likely to cause some decline in the yield from the remaining modes if any mode of operation is abandoned.

Some fish are discarded at sea. These fish incur fishing mortality even though they are not represented in the catch. One estimate (IATTC, 1993: 3) puts discards, by weight, of tunas during log fishing as high as 32.5%; 8.6% for school fishing and 0.7% for dolphin fishing. If these figures are valid we are likely to underestimate the effect of log fishing on other modes. Catches would be greater than the model suggests when log fishing is eschewed, and less when dolphin fishing is foregone. This effect is being investigated, but we have no results ready for discussion.

The effects of redirecting effort from dolphin fishing are similar to those obtained by Punsly et al. (1994) using a spatially aggregated model. If there had been no fishing on dolphin then catches of yellowfin would have been less for almost every month in the period considered, with the decline being greater in the latter part of the period when more dolphin fishing occurred. This decline would have been compensated by an increase in catches of skipjack, bringing the total for both species to within 2% of that predicted for the entire period with dolphin fishing as observed. The similarity of the results of the two studies suggests spatial effects are not crucial in this case. This is interesting because a concern the previous study was unable to answer was that the cessation of dolphin fishing might cause the fishery to contract its geographical range. If so, its yield would probably decline (Mullen, 1994). Anganuzzi's effort allocation program (Anganuzzi, 1996), however, suggests the range of the fishery would not contract, so the problem does not arise.

Log and school fishing were considered a single mode by Punsly et al. (1994). The effects of switching from log fishing suggested by this body of work are at first surprising, but easily explained. It was anticipated that catches of yellowfin would initially decline, but would recover after a delay, so that the overall effect on yellowfin would be positive. The model predicts instead that catches are immediately enhanced, and that the overall effect on catches is positive. However, when skipjack are added, the total catches do show an initial decline, followed by a recovery to roughly the catches predicted without changing fishing mode. Log fishing generally yields more skipjack, and there was a lot of log fishing in 1980, 1981 and 1982; catches of skipjack would have declined substantially in those years without log fishing. Effort is redirected to school and dolphin fishing, for which the catch of yellowfin is higher, that is why there is an immediate increase in the catch of yellowfin. During 1984-86, there was little log fishing, so little effort to redistribute from that mode. If the population had been more heavily exploited during the period considered then the recorded catches of yellowfin might indeed have declined more. Then there would have been more scope for improving the yield per recruit.

If fishermen had forgone both log and dolphin fishing, the catches of yellowfin would have declined immediately. Catches of yellowfin under this scenario only rarely equal or surpass those that were predicted with the observed fishing modes. Under this scenario, there is no compensation for reduced catches of yellowfin by increased catches of skipjack.

Turning now to Table 1, we can consider how individual categories of vessels might have fared. To preserve the confidentiality of the data supplied on voluntary basis by vessel owners and skippers, the identity of individual categories is not revealed. Ignoring the entries marked with an asterisk as representing too few data, there are two points that can be made. Firstly, if vessels had not fished dolphins then the catch of yellowfin would have declined for all but one category (B) in both the segments of the period. Presumably boats of categories that are unable to operate in this mode would suffer from increased competition for yellowfin unassociated with dolphins, which tend to be smaller. Secondly, increased catches of skipjack would have more or less compensated for the reduced catch of yellowfin in the earlier segment (1980-83) when log fishing was clearly a viable alternative. In the later segment, vessels of category B would have been able to make up the shortfall of yellowfin, while the others would not. For all boats combined, catches of yellowfin would have declined and those of skipjack would have increased in both segments of the period. Combined catches of both species for all boats would have increased by 6% in the first segment of the period, and declined by 5% in the second.

The case when no boats fished logs is almost the opposite of that when they eschewed dolphin fishing: catches of yellowfin would have increased for most categories, but the overall benefit would be reduced due to lower harvest of skipjack. For two categories, K and L, there would have been a marked decline in the total catch during 1980-83 when the incidence of log fishing was high.

Most categories suffer reduced catches if they forego both log and dolphin fishing, but one exception to this generalisation is particularly interesting. Category B does better in catching yellowfin and skipjack if there is no log or dolphin fishing than in any other circumstances. An increased yield per recruit can explain enhanced yield when there is no fishing of logs, but not an enhancement due to cessation of dolphin fishing. It seems that boats of category B would have done better if they had ignored tunas associated with dolphins. Thus, boats of category B were not maximising their overall yield and might have been attempting to optimise according to other criteria. For all vessels combined, catches of yellowfin declined substantially in both segments of the period. Total catches of skipjack also declined in the first segment, but increased in the second. There was a decline in the combined total catches throughout the period without log or dolphin fishing, and that decline was greater in the first segment of the period.

This work might be extended in a number of ways. Anganuzzi (1996) has discussed modelling the allocation of fishing effort on the basis of individual vessels, rather than using a mass-action type of model. A general linear model of the type used by Punsly and Deriso (1991) could then be used to determine a factor accounting for the fishing power of each vessel-captain combination. Punsly and Deriso (1991) found significant effects due to time-region strata, but did not find any significant effects due to environmental variables such as wind-speed. It would be interesting to run the analysis of Punsly and Deriso (1991), ignoring effects of time-area or time-region strata, and considering only vessel-

skipper and environmental effects. The catchability coefficient would then pertain only to the area of water, and any spatial variations would be determined solely by environmental relationships. This would allow, in principle at least, catchability coefficients to be defined for time-area strata within which no effort was expended. It might still be necessary to assume zero or much-reduced catchability for some strata on the basis of environmental conditions. If so, those strata would be truly off-limits to fishing. The aim of the work would be to assign variation in catch rates to the power of the fishing vessel, environmental conditions, and then to the distribution of fish.

5. CONCLUSIONS

A discussion of the effects of curtailing modes of fishing in a particular year cannot be divorced from the peculiarities of that year. Some years are bad for fishing logs, in those years little is sacrificed if logs are passed by. In years that are very good for fishing logs, less will be lost if boats do not fish dolphins. The effects will also vary among categories of vessel. Vessels that cannot fish dolphins may suffer from increased competition if other boats switch from that mode of operation.

In considering the effects of vessels forgoing dolphins as an aid to fishing tunas with purse seiners in the eastern Pacific Ocean, this model confirms the results of a simpler aggregate model. The harvest of yellowfin is likely to be reduced, but additional catches of skipjack are likely, so the yield of both species combined is unlikely to change much.

In switching from fishing logs, increased catches of yellowfin are likely at the rates of exploitation used in this model. But skipjack catches are likely to decline more markedly, causing a reduction in the catch of tunas from the region by this fishery.

The model is complex enough to have provided some surprises for which rational explanations have been made. Unfortunately the natural system is far more complex, and any one of the many simplifications made in the model might mask a phenomenon which is crucial to any quantitative predictions.

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INTERACTION BETWEEN VESSELS FISHING FOR YELLOWFIN TUNA (*THUNNUS ALBACARES*) IN THE NORTHEASTERN AND SOUTHEASTERN PACIFIC

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ABSTRACT

An analysis of possible interactions between purse seiners searching for tuna in the northeastern and southeastern Pacific is reviewed mainly with information on total catch of juveniles (length < 80 cm) and adults (length > 80 cm) in different areas of the fishery and also through statistical correlation. It is shown that large catches of juveniles in some areas could have a negative effect in adult catches in other areas, some years later. These results are preliminary and more research on this field should be encouraged.

1. INTRODUCTION

In the eastern Pacific Ocean (EPO) there are a multiplicity of fleets and nations involved in harvesting yellowfin tuna (*Thunnus albacares*) and skipjack tuna (*Katsuwonus pelamis*). Yellowfin is the most important species taken by the surface fishery in the EPO (70%) and skipjack is the second most important species (20%), other species taken include bluefin tuna (*Thunnus thynnus*), bigeye tuna (*T. obesus*), albacore tuna (*T. alalunga*), bonito (*Sarda chiliensis*) and black skipjack (*Euthynnus lineatus*).

In the EPO, fishermen detect tuna in several ways depending on the fishing mode employed, that we can summarize in three principal groups: marine mammal-associated schools, free-swimming schools and log schools (associated with floating objects). Furthermore, there are also differences among fishing modes in the size composition of yellowfin and in fishing areas. For several purposes the purse seine fishery is treated as being made up of two fishing modes, marine mammal-associated schools, and free-swimming and log schools combined (Allen and Punsly, 1984).

The marine mammal schools (tuna associated with dolphins) are composed principally of adult tunas (> 80 cm, > 10.4 kg) with a large size distribution, but different composition in the number and species of associated dolphins. The free-swimming schools are common in coastal waters and composed principally of juvenile tunas (frequently associated with skipjack). Log schools are composed essentially of very young tunas, in association with other species as skipjack and present mainly south of the EPO.

From 1985 to 1992, the indices of abundance for yellowfin tuna in the EPO show increasing trends, and the catches since 1984 have been even greater than expected (IATTC, 1992b). This was due in part to the fishery concentrating on catching larger fish.

Wild (1994) estimated that 36% of the increase in the abundance indices is explained by the reallocation of effort toward the older and larger fish in the stock. However, if the fishermen were to revert to catching mostly juvenile fish (<80 cm, <10.4 kg) the abundance and catches of yellowfin might be substantially reduced. Based on recruitment levels, age-specific catchability coefficients for tuna caught without dolphins and average fishing effort observed during 1980-88, Punsly et al. (1994) predicted that yellowfin catches would be reduced by an average of about 25%.

There are a number of possible interactions that may exist between and among the various tuna fleets operating in the eastern Pacific. Kleiber (1994) noted that interaction can occur between fisheries harvesting the same or different size classes or life stages of the target species. Because in the last ten years the dominant type of school in the whole fishery, has been tuna associated with dolphins, thereby we can assume that the stock conditions can be damaged if the predominant type of school is changed with an effect in the tuna size and the juvenile mortality.

2. TRENDS IN RECENT STATISTICS ON YELLOWFIN IN THE EPO

2.1 Mexican Purse Seine Fishery

Until 1985 the extent of the Mexican tuna fishing operations was a direct result of the size and autonomy of the Mexican fleet. The fleet generally concentrated on free schools of yellowfin tuna, which are particularly abundant near the Mexican coastline.

Since its rapid development in the last ten years, the practice of the Mexican tuna fishing fleet has been to operate for the most part in the Exclusive Economic Zone (EEZ) of Mexico and its adjacent areas. Mexican ships seldom operate south of 5°N or west of 135°W (Figure 1). A feature that differentiates current operations of the Mexican fleet is that Mexico now concentrates on marine mammals schools; second in importance are yellowfin tuna travelling in free-schools (Figure 2). These fishing practices are mainly determined by bio-geographical considerations since in the oceanic area off Mexico the available tuna is mainly associated with dolphins as was shown by Au (1991). Despite its presence as one of the most prevalent species in the EPO, there are two main reasons for not catching skipjack tuna (Figure 3). One of them is that the concentration of skipjack varies a lot in the north, where the Mexican fleet prefers to operate due to logistics and expenses. The other reason is because there are fewer floating objects (e.g., logs) on the water than in the south of the EPO.

2.2 International Purse Seine Fishery

Other countries operating in the EPO zone, are Venezuela, Vanuatu, Ecuador and the United States of America. Sometimes they fish north and west of the Mexican EEZ, but most of the tuna catch is taken south of 5°N. Apart from sovereignty reasons, there are probably economic considerations. The international concern for dolphin protection causes principally to those fleets (other than the Mexican fleet) to redirect some effort back from marine mammal schools to free swimming or log schools (IATTC, 1993). In 1993, the IATTC issued 133 "dolphin safe" certificates to purse seine vessels verifying the fact that marine mammals schools had not been encircled during fishing operations (IATTC, 1994).

That number of allowed certificates is higher in comparison to previous years. For instance, 24 in 1990, 67 in 1991 and 88 in 1992 were issued (IATTC, 1992a; 1992b; 1993; 1994). Due to this redirection of effort, the number of dolphins sets made in the southeastern Pacific, on marine mammal schools decreased (Table 1). The estimated total effort, on marine mammal schools was reduced by 33% in 1993 as compared to 1992 (IATTC, 1993).

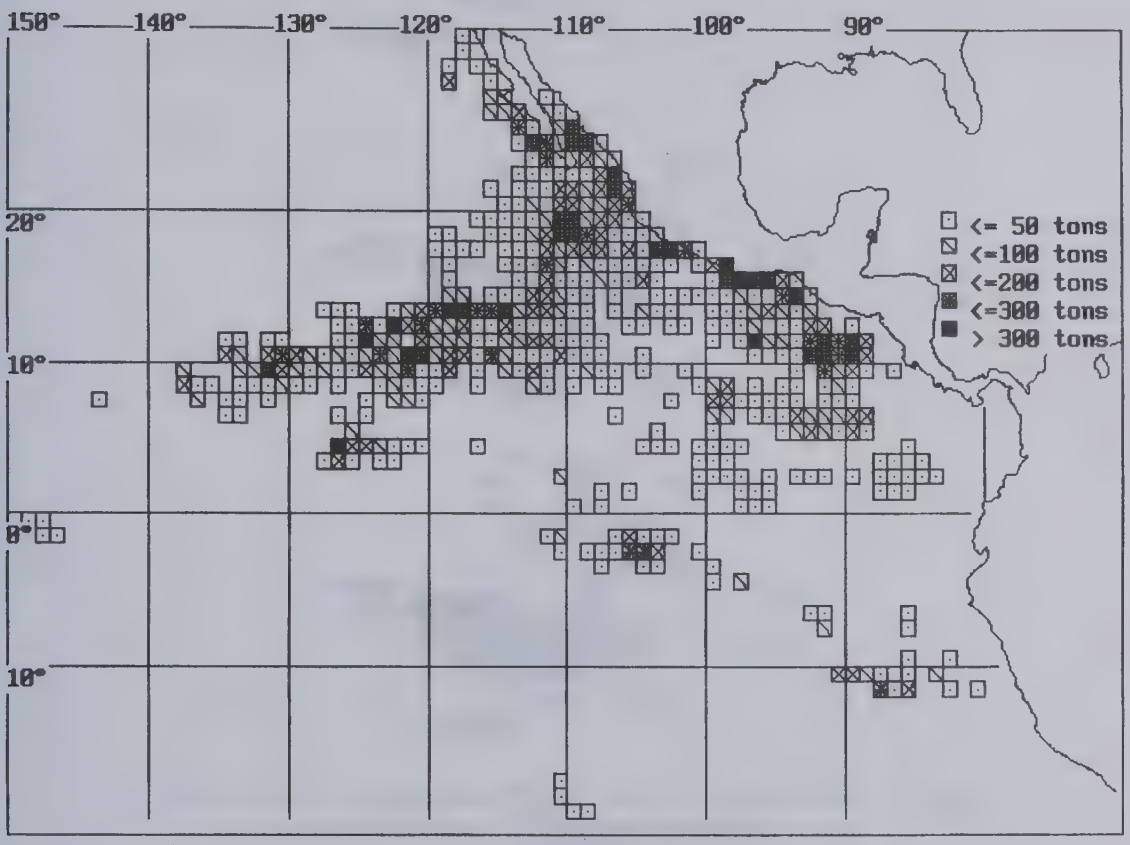

Figure 1. Yellowfin tuna catch in the EPO by the Mexican tuna fleet in 1994. (Data from Programa Nacional de Aprovechamiento del Atún y de Protección de Delfines (PNAAPD).)

Table 1. Number and percentage of three types of purse seine sets separated by Mexican and non-Mexican fleet. MM=marine mammal-associated school, FS=free school, LS=log set. (Data from PNAAPD and IATTC.)

		Mexican		Non-Mexican		
		No.	%	No.	%	Total
1992	MM	5,932	61.1	3,777	38.9	9,709
	FS	1,710	28.1	4,389	71.9	6,099
	LS	183	9.3	1,779	90.7	1,962
1993	MM	3,541	53.2	3,119	46.8	6,660
	FS	3,376	39.5	5,161	60.5	8,537
	LS	281	15.8	1,496	84.2	1,777
1994	MM	4,600	76.8	1,384	23.2	5,948
	FS	2,116	36.6	3,670	63.4	5,786
	LS	379	27.7	1,371	78.3	1,750

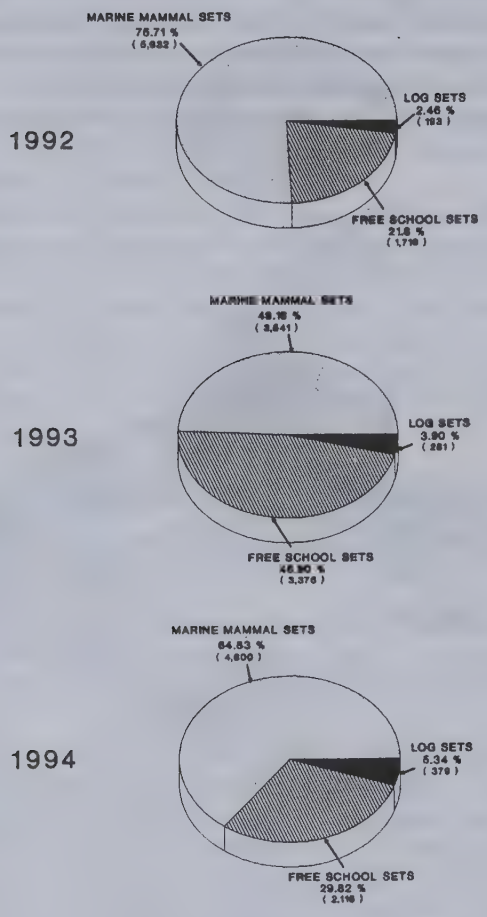

Figure 2. Mexican tuna fleet set type 1992-94, percentage and number of sets. (Data from PNAAPD and IATTC observer programs.)

2.3 Size Composition of the Catch

Length-frequency samples of yellowfin tuna are collected by IATTC personnel at ports of landing. Histograms showing the estimated catches by gear, year and area appear in the Annual Reports (IATTC, 1987; 1988; 1989, 1991; 1992a; 1992b; 1993). The length frequency samples are stratified by market measurement areas. The areas used by IATTC appear in Figure 4.

The length composition of yellowfin tuna caught by the purse seine fishery is similar in different years, except 1988 (Figure 5) but there are some important differences among the areas (Figure 6 a to g). For instance, Areas 4, 5 and 6, the zone of operation of the international fleet, show in most years higher catches of juvenile fish (less than 80 cm) compared to adult fish (over 80 cm) than others areas and the percent juvenile catch combined from these same areas goes from 59% to 79%. For some years in Areas 1,5,6

and 8 more than 50% of the catch, was less than 80 cm in length. In Areas 1 and 8 these juvenile catches correspond principally to non marine mammal schools. Sets by the Mexican fleet are done mainly on free swimming schools seldom associated with skipjack and in the other areas, where the international fleet operates, there are principally catches of juveniles frequently associated to skipjack or in log schools, in both cases there are very young tunas.

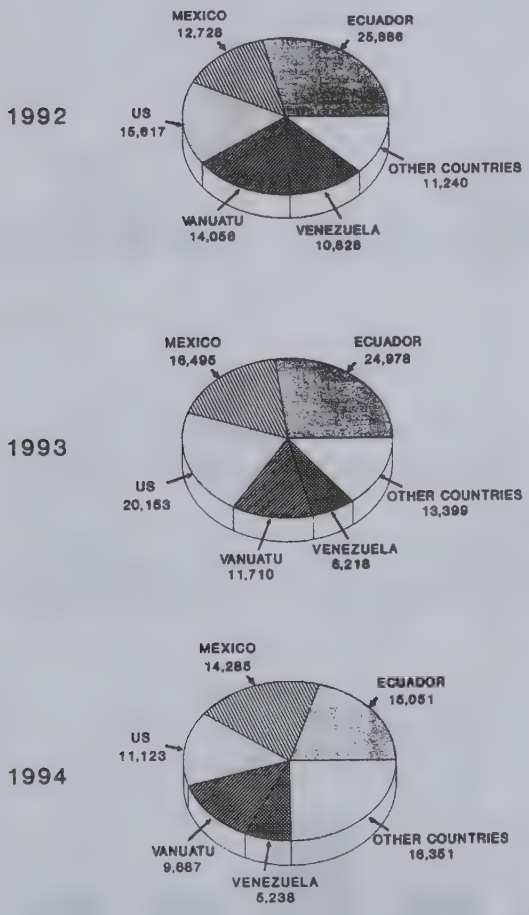

Figure 3. Skipjack tuna catch by country, 1992-94. (Data from IATTC.)

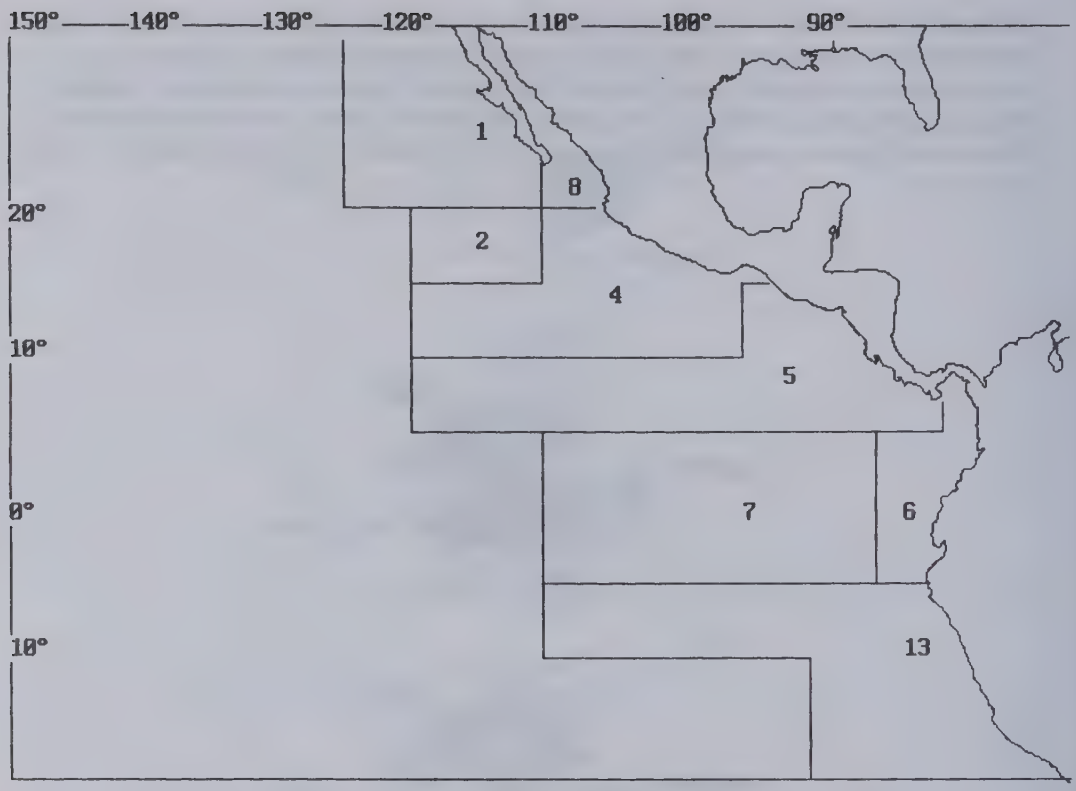

Figure 4. Area used by the IATTC for sampling lengths of tuna in the EPO.

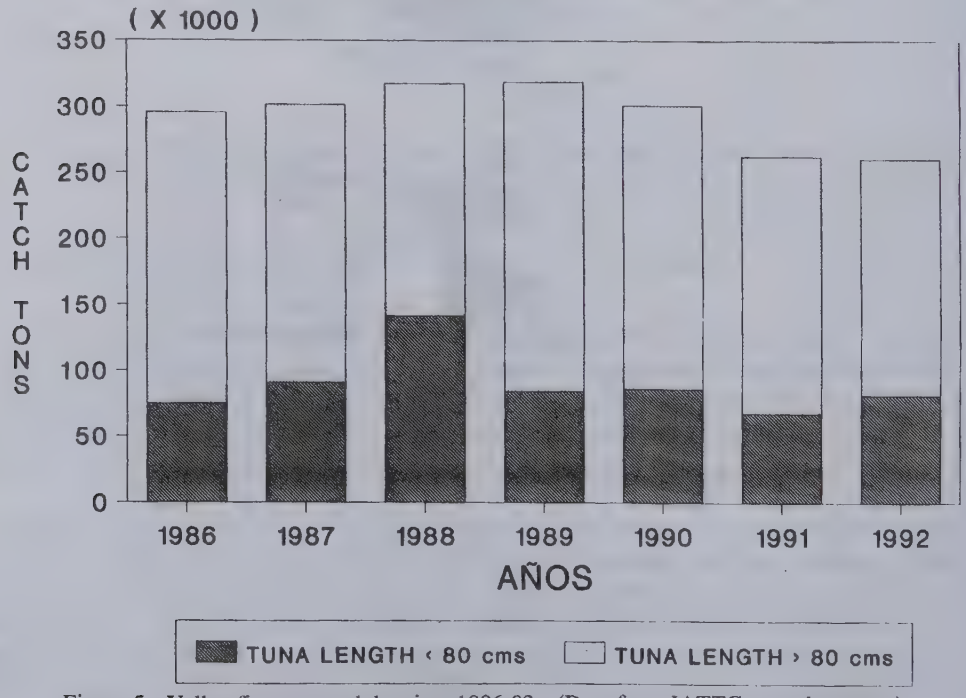

Figure 5. Yellowfin tuna catch by size, 1986-92. (Data from IATTC annual reports.)

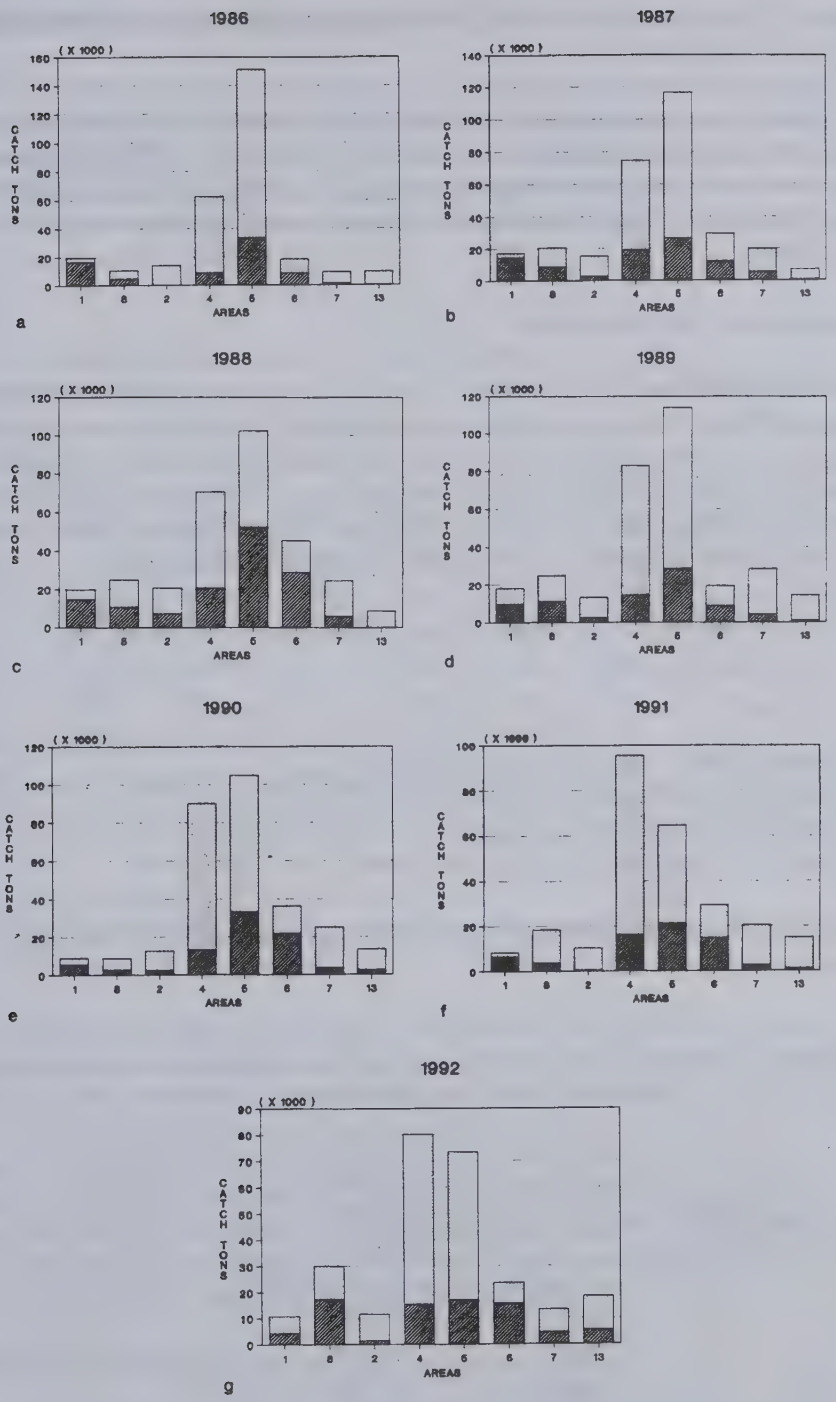

Figure 6. Yellowfin catch by size and area, 1986-89. (Data from IATTC annual reports.)

3. INTERACTION BETWEEN THE NORTHEASTERN AND SOUTHEASTERN PACIFIC FISHERIES

The effect of fisheries in one EEZ on catch rates in another EEZ is particularly important for countries with domestic fleet operating mainly in their EEZ and adjacent areas. The recent relocation of fishing effort toward no marine mammal schools by the international fleet caused concern among the Mexican shipowners that their catch rates would be affected.

3.1. Inference on the Interaction

As previously mentioned in the section 1 and 2.3 the difference in dominant fishing modes has an effect on the size composition of the catch. As a way to detect the effect of increasing catches in non marine mammal schools, a multiple regression analysis between average weight (kg) of yellowfin in EPO (Tomlinson et al. 1992 and IATTC, 1993) and catches among different type sets (IATTC, 1994), was done with a time series from 1961 to 1993. The results are shown in Table 2 and in the following equation:

$$W = 12.9726 + 0.0000529\ (D) - 0.0001444\ (L) - 0.0000439\ (F)$$

where:

W = Average weight of yellowfin tuna in EPO
D = Catch of yellowfin tuna in marine mammal sets
L = Catch of yellowfin tuna in log sets
F = Catch of yellowfin tuna in free school sets

It is clear that the largest decrease in average weight, at equal catches in the three type sets, corresponds to the log catches.

Table 2. Analysis of variance of the multiple regression between the mean weight and the catch of yellowfin tuna in three different types of sets.

	DF	Sum of squares	Mean square
REGRESSION	3	187.62459	62.54153
RESIDUAL	29	61.25556	2.11226

F	29.60881
Signif F	0.00001
Rsquare	0.75388

3.2 Correlation Between Juvenile and Adult Catches by Areas

A correlation between juvenile and adult catches was made in the IATTC areas (Figure 4) with two years lag between them, to look for a possible relation due to growth, if young tunas in some areas would migrate and found as adults elsewhere. A significant negative correlation index (-0.9531) was obtained only between juvenile catches in area 5 and the adult catches two years later in area 8 (Table 3). This result should be taken with caution due to the lack of enough annual data.

Table 3. Correlation between juvenile and adult yellowfin catches in IATTC areas with a 2-yr lag between them. A# = area, J = juvenile tuna, A = adult tuna, * = <0.01 significance.

	A1A	A2A	A4A	A5A	A6A	A7A	A8A	A13A
A1J	0.0744	0.7243	-0.3096	0.3495	0.6987	0.8225	-0.1874	-0.6051
A2J	-0.2392	-0.5100	0.6826	0.4735	-0.0279	0.2773	-0.9320	0.1411
A4J	-0.1299	-0.6713	0.5524	0.5789	-0.1300	0.5122	-0.5224	0.6031
A5J	-0.3365	-0.0568	0.2273	0.1740	0.2696	0.1042	-0.9531 *	-0.4375
A6J	-0.0078	-0.4244	0.3438	0.3692	-0.3241	-0.1507	-0.9026	-0.0090
A7J	-0.0080	-0.7119	0.8383	0.6215	-0.2942	0.3947	-0.5982	0.6117
A8J	-0.5151	-0.3808	0.7934	0.2123	0.4190	0.6883	-0.3290	0.3216
A13J	0.2645	-0.4124	-0.1026	-0.2521	-0.8005	-0.9076	0.2510	0.3662

4. DISCUSSION

As was mentioned by Suzuki (1994) it is obvious that the interactions among the fisheries on yellowfin tuna are more complicated than previously assumed. An important aspect is the environmental changes which can affect the vulnerability of yellowfin tuna (Wild, 1994). In this particular case, the knowledge of yellowfin tuna migrations in EPO is inadequate especially for adult tunas (Deriso et al., 1991). Nevertheless, our results should make us aware that interactions might not always be found at a global scale but can nevertheless exist at a smaller scale. For those reasons a predominant juvenile size on the harvest of yellowfin tuna could affect the yield in other areas, although this has to be corroborated with further studies and a longer series of data.

5. ACKNOWLEDGEMENTS

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INTERACTION BETWEEN MEXICAN LONGLINE AND PURSE SEINE FISHERIES FOR YELLOWFIN TUNA IN THE EASTERN PACIFIC OCEAN

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ABSTRACT

The Mexican longline and purse seine fisheries logbook records from 1984 to 1990 were analysed to define a possible interaction between these two gears. Effort of the two fleets overlapped in only 37 1-degree squares by month during 1988. The seasonal peak fishing success for longline and purse seine differs. Although the information was not enough to define an interaction between gears, it is possible to suggest the presence of a "consecutive" interaction based on the analysis of length distribution. Longline catch rates were higher when the thermocline was deeper and could be one of the factors enhancing a possible interaction.

1. INTRODUCTION

Since the rapid development of the Mexican purse seine fleet in the eastern Pacific Ocean (EPO) in the 1980s, its participation has been important as much in volume of catch as for its carrying capacity. The Mexican fleet has maintained first place in tuna landings for the EPO since 1986 (IATTC, 1987, 1988, 1989, 1990, 1991, 1992a, 1992b, 1993, 1994).

In order to develop good management strategies for tuna fisheries, in recent years many governments have become interested in identifying the major types of interactions, the scientific problems related to them, and in reviewing interaction methodology (Shomura et al., 1994).

Yellowfin tuna in the EPO are considered to be a single stock and are fished primarily by purse seine. Additionally, yellowfin are also caught by a limited number of baitboats, longliners and trolling vessels (Shomura et al., 1994). Considering an interaction can occur between two fisheries operating in overlapping or separated fishing grounds and between fisheries harvesting the same or different size classes of life stages of the target species (Kleiber, 1994), one could postulate a potential exists for interaction between the different kind of gears in the EPO.

The interaction between the surface and longline fisheries in the EPO has been discussed by Suda and Schaefer (1965), Kume and Schaefer (1966), Kume and Joseph (1969), Shingu et al. (1974), Suzuki et al. (1978), Miyabe and Bayliff (1987), and Nakano and Bayliff (1992). In those studies the information of the Japanese longline fleet was used. The surface and longline fisheries have not fished in exactly the same areas. Also,

fish caught by longlines are almost entirely large, whereas the surface fleet captures smaller yellowfin tuna (Nakano and Bayliff, 1992; Wild, 1994).

Although the Mexican longline fleet stopped fishing in 1990, it is important to examine the longline and purse seine interaction because of the possibility of future removal of the longline ban and the current existence of foreign longline fishing outside of Mexico's EEZ in the EPO.

2. MEXICO TUNA FISHERIES

2.1 Purse Seine

The Mexican purse seine fleet began in the 1960s, but its greatest development was in the 1980s. From 1984 to 1990 the fleet averaged 50 vessels annually, and individual vessels had carrying capacities that ranged between 350 and 1,270 mt. The most important were vessels in the 1,090 ton class (Ortega-García et al., 1992). The main species caught by the Mexican purse seine fleet has been yellowfin tuna (Table 1).

Table 1. Catch of main tuna species in the eastern Pacific Ocean by Mexican purse seine fishery from 1984 to 1990. Unit = metric tons.

	YELLOWFIN TUNA	SKIPJACK TUNA	OTHERS
1984	53,884	9,794	1,601
1985	80,591	6,148	1,298
1986	105,304	8,003	553
1987	99,355	6,625	626
1988	105,659	18,706	6,588
1989	118,137	18,129	11,426
1990	117,501	7,608	10,644

Data source: IATTC, 1984, 1985, 1986, 1987, 1988, 1989, 1990, 1991.

2.2 Longline

The Mexican longline fishery began in 1980 with 11 vessels. By 1986, this fleet had 21 vessels with carrying capacities that ranged between 120 and 200 mt; each vessel fished from 120 and 2,500 hooks per day.

Although the target species of the longline fishery has been billfish, yellowfin tuna have been recorded in their catch (Macías-Zamora, 1993; Squire and Muhlia-Melo, 1993). Since billfish constitute an economically important resource, and one that is productive for recreational purposes, the Mexican government established protective measures to prevent over-exploitation of the billfish stocks. In 1972 the Mexican government established a sportfishing zone, which extended from the coastline to 30 nm offshore. In 1983, this zone was extended to 50 nm offshore. Following strong complaints by sportfishing operators, new regulations were issued in August 1987 that restricted longline operations to the

offshore areas of Mexico's 200-mile zone; also additional protection areas were decreed (Squire and Au, 1990). Although the Mexican government cancelled permits for longliners in 1990, there are currently requests to re-establish this fishery.

2.3 Baitboat

Although the baitboat fishery is one of the oldest tuna fisheries in Mexico, its catch is relatively small compared with that of the purse seine fishery. The baitboat vessels are small, with a carrying capacity between 80 and 110 mt. During 1984 to 1990, the average number of active vessels was 12. The operational fishing area is limited to the west coast of Baja California and Islas Revillagigedo. As purse seiners also operate in this area, there is a potential for local interaction.

2.4 Troll and Artisanal Gear

Yellowfin tuna are also caught by the sport and artisanal fisheries. Although there is no systematic recording of the catches, the volume of fish taken by these fisheries is reported to be small.

3. METHODS

The information analysed was from the logbook records of the Mexican purse seine and longline fleets from 1984 to 1990. For the analysis of a potential interaction between the two gears, the information for 1988, because of its completeness, was used. Unfortunately, because of the lack of long time series of data it was not possible to apply the types of simulation models used by Boggs (1994) to detect the existence of an interaction between fisheries.

To compare the lengths of yellowfin tuna caught by both kinds of fishing gear, the areas determined by the Inter-American Tropical Tuna Commission (IATTC) were used (Figure 1). The weight data of yellowfin tuna caught by longline gear during 1988 was converted to length using the weight-length relation determined by Chatwin (1959). The length frequency recorded by the IATTC during 1988 for the yellowfin caught by the purse seine fleet was used for this comparison.

For the interaction analysis, the overlapping area, i.e., the zone where both fleets operated during the same month, was used. For this, the average monthly catch per standard day was used for the purse seiners and the average monthly number of yellowfin tuna caught by 100 hooks per month for the longliners. The standard effort for the Mexican purse seine fleet was estimated applying principal-component analysis as described by Ortega-García and Gómez-Muñoz (1992).

Taking into account that vertical thermal structure has an important effect on tuna distribution (Kawai, 1969; Suzuki et al., 1977) and that this environmental factor could have an effect enhancing the conditions for a major interaction between two gears, the profiles of temperature for the overlapping zone (averaged over the time of overlap) were analysed using a bathythermograph database consisting of data collected by fishing

(commercial), military, and research vessels and tabulated by the National Marine Fisheries Service.

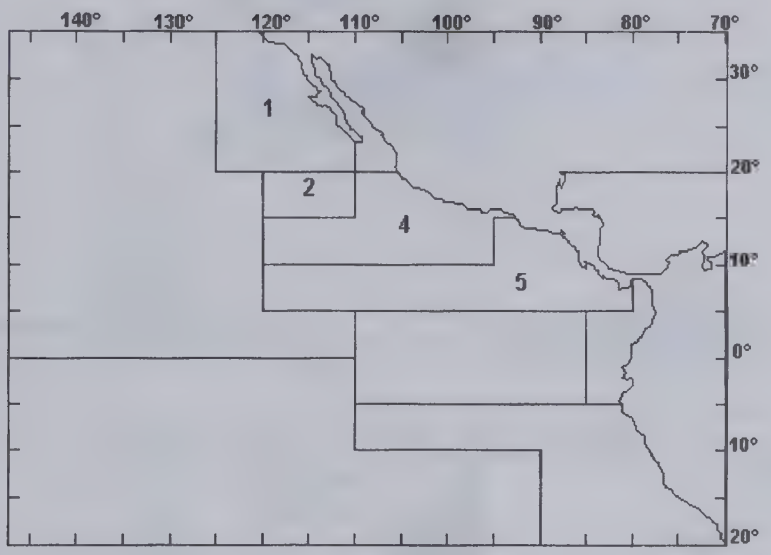

Figure 1. Areas used for sampling length of yellowfin tuna caught by the purse seine fleet in the EPO. Source: IATTC, 1989.

4. RESULTS

4.1 Longline Fishery

The fishing effort (number of hooks) distribution from 1984 to 1990 is shown in Figure 2 (top). The areas of greatest intensity were around Islas Revillagigedo and the mouth of the Gulf of California. However, in these areas the catch rate (number of yellowfin per 100 hooks) had low values; the highest values were found along the 10° north latitude line (between 94°-108° W.) as shown in Figure 2 (bottom).

Billfishes were the most significant portion of the catch (64%), while sharks made up 16.9% and tunas 7% of the catch. Among the tunas the yellowfin was the most important making up 94.3% of the tuna catch.

The size composition of the catch during 1988 is shown in Figure 3. The size of yellowfin tuna caught by the longline fleet was between 50 and 185 cm, although the length frequencies varied with fishing location. The fish caught in Area 1 were between 50 and 160 cm, with a prominent mode at 100 cm. In Area 2 the mode was at 130 cm and the average weight was 40 kg. Most of the fish caught in Area 4 were between 110 and 140 cm with a prominent mode at 120 cm. This mode was the same for fish caught in Area 5. The average weight was similar at 32 kg (Area 4) and 34 kg (Area 5).

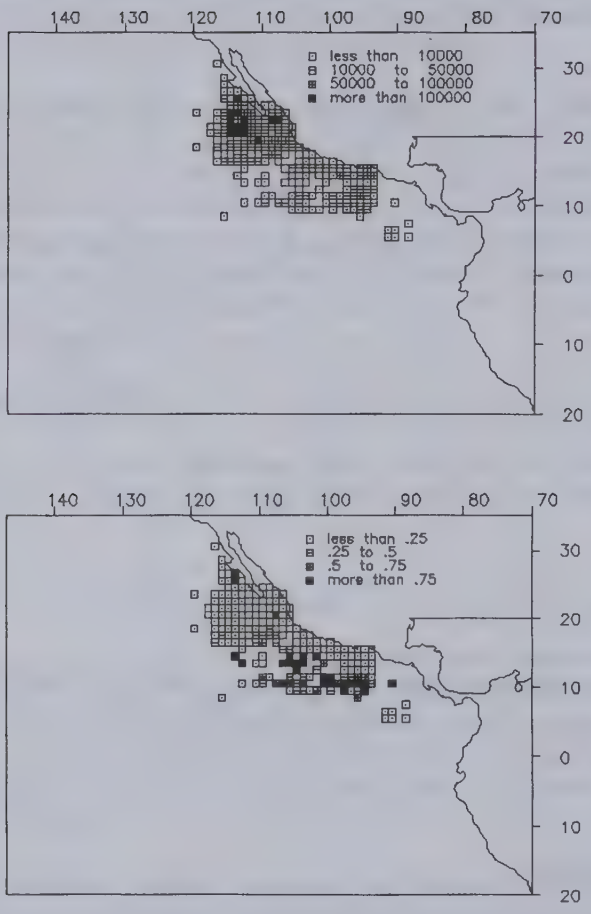

Figure 2. Mexican longline fishing areas from 1984 to 1990. Top, fishing effort distribution, in number of hooks. Bottom, catch rate distribution, in yellowfin tuna per 100 hooks.

4.2 Purse Seine Fishery

The distribution of catches of yellowfin tuna from 1984 to 1990 for the Mexican purse seine fleet is shown in Figure 4. The fleet had the highest catch in nearshore areas, primarily around the Gulf of California, along the Mexican Pacific coastal waters, and along the 10° north latitude line (between 98° and 109° W.).

The samples taken by the IATTC during 1988 show most of the fish caught in Area 1 were between 46 and 94 cm in length, with a prominent mode centred at about 66 cm. In Area 2, most of the fish caught were between about 48 and 160 cm; the most prominent mode was centred at about 90 cm. In Area 4 the size range was about the same as in Area 2. There are three modes of about equal prominence at approximately 76, 92, and 112 cm. The size range for Area 5 was about the same as for areas 2 and 4. The most prominent

mode is centred at 52 cm, with lesser modes at about 70 to 80, 90 to 94, 110 to 120, and 140 to 150 cm (IATTC, 1989).

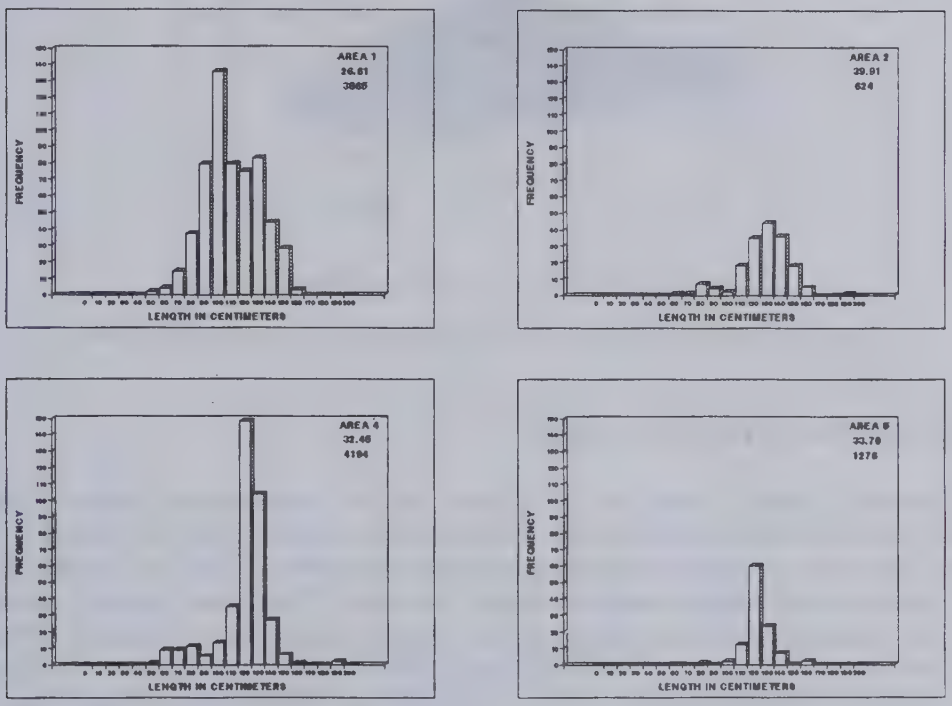

Figure 3. Length frequencies of yellowfin tuna caught by Mexican longline fishery during 1988. Also shown are average weight (kg) and number of fish in the sample.

4.3 Overlapping Zones

During 1988, longline and purse seine effort overlapped in 37 1-degree square by month strata among which there were 30 unique 1-degree squares. Average longline and purse seine catch rates for these squares are shown in Figure 5. These are all in IATTC Areas 2 and 4. Considering the size distribution of yellowfin tuna caught by longliners (Figure 3), this implies that most of the fish in the overlapping zone were larger than 120 cm. For both fleets, the squares of highest catch rate in 1988 are mostly not among the 30 overlapping squares (Figures 2, 4 and 5). The season of highest catch rate are likewise separated (Figure 6).

The average temperature profiles in the overlapping zone for three levels of catch rates for the longline fishery (Figure 7) shows longliners obtained better catches where the average temperature of the mixed layer was higher and the thermocline deeper.

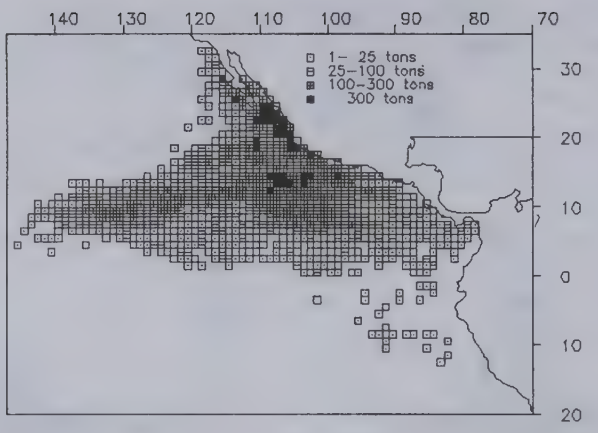

Figure 4. Catch distribution of Mexican purse seine fleet from 1984 to 1990.

5. DISCUSSION AND CONCLUSIONS

The area of greatest intensity of fishing effort for longliners has been reported as one of the areas with the highest catch per unit effort for striped marlin (Squire and Suzuki, 1990). The Japanese longliners operated in this area from 1981 to 1987 and applied fishing effort that exceeded 500,000 hooks per quarter each year. These areas, primarily around Islas Revillagigedo, have been reported by the Japanese longline fishery as areas of high catch for striped marlin, swordfish, black marlin, sailfish, and shortbill spearfish; the catch rate (catch/100 hooks) exceeded 0.1. The catch rate was 1.0 for bigeye and less than 1.0 for yellowfin tuna (Nakano and Bayliff, 1992). In this study, the values of catch rates in these areas were generally less than 0.25, which is a low value considering purse seiners catch the largest amounts of yellowfin in these areas (Calkins, 1975; Orange and Calkins, 1981). The 1-degree areas with more than 100 tons of average annual catch from 1984 to 1990 are shown in Figure 4.

Bearing in mind that the longline catch and hook rates are not necessarily reliable indicators of abundance of yellowfin tuna because the Mexican fishery tried to catch billfish primarily and the number of yellowfin tuna caught was small compared with other species, it is important to know if the fishing areas overlap when the two kinds of gear were operating and what amount of yellowfin tuna was caught.

Although this analysis used the 1-degree squares where the two kinds of gear operated in the same month, the information was insufficient for a comprehensive study of longline and purse seine interaction. Based on the results of length distribution, one can suggest a "consecutive" type of interaction, i.e., an impact on longline fishery occurs some time after the purse seine fishery catches yellowfin tuna. In agreement with Kleiber (1994), it is not necessary for two fisheries to target the same size range or life stage of the fish for competitive interaction to occur. If fish are exposed to a series of fisheries as they grow in size or pass through stages of their life cycle, a consecutive interaction could be present. In this case, it could be possible the interaction occurs even if effort does not overlap in time. Furthermore, given that tuna can migrate from one area to another or exchange diffusively

between two regions, it is possible for these fisheries, located at some distance from one another, to interact competitively (Kleiber, op cit).

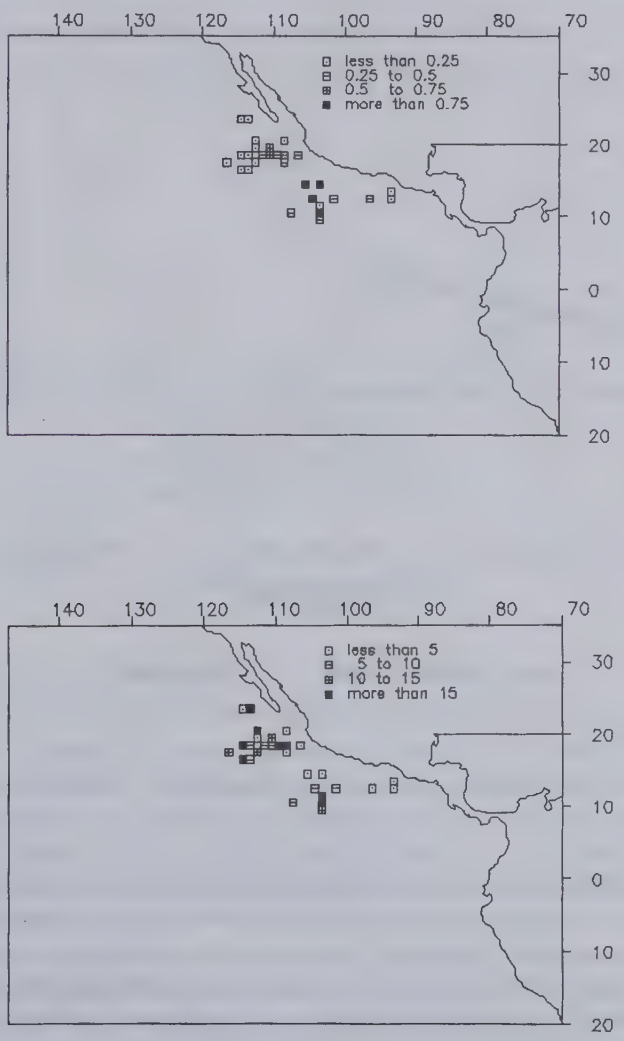

Figure 5. Catch rates in overlapping areas for Mexican longline and purse seine fisheries during 1988. Catch rates in each square are averaged over the whole year. Top, longline, in yellowfin tuna per 100 hooks. Bottom, purse seine, in tons per standard day fishing.

It is obvious there are a number of factors playing important roles in the interaction between longline and purse seine fisheries, including factors related to the physical environment. Of these, temperature could be one of the most important influences on tuna distribution (Kawai, 1969; Suzuki et al., 1978; Sund et al.,1981). Green (1967) showed a combination of sharp gradient and shallow thermocline gave the highest success rate in purse seine fishing. In this study, we found the catch rate for longliners was higher when the average mixed layer temperature was high (which was expected if we consider in this

the thermocline is deeper and yellowfin could be more vulnerable to fishing with this kind of gear). If the mixed layer temperature is higher, yellowfin tuna could be in deeper waters. This factor could enhance a possible interaction.

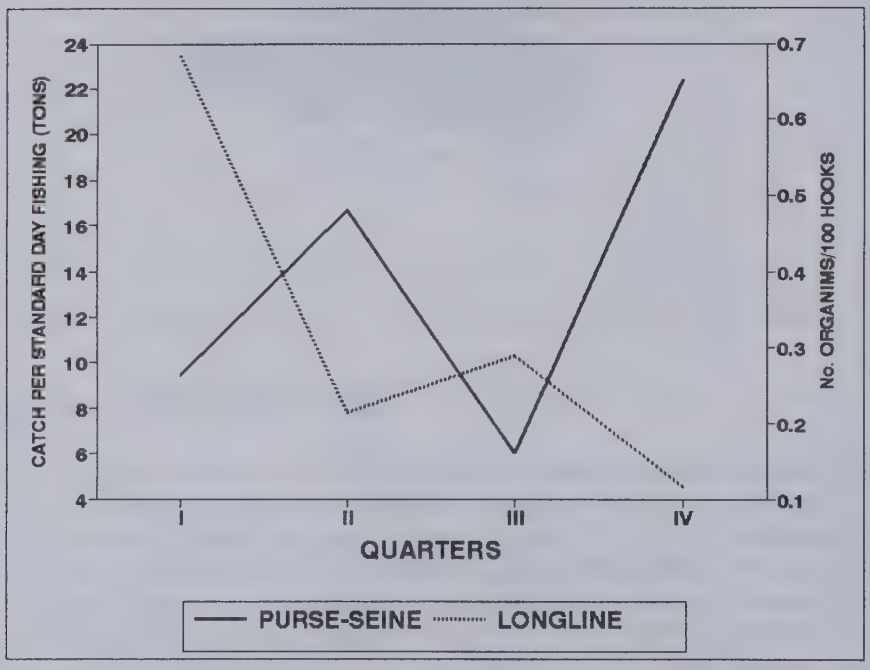

Figure 6. Seasonal fishing success in the overlapping areas for longline and purse seine.

Although the longline catch rates of yellowfin tuna were lower, a large number are fish having the same size as those caught by the purse seine fleet. At present, the Mexican longline fleet is not operating because of problems with its interaction with recreational fishing. In the event the Mexican longline fishery resumes fishing operations, it may try to avoid problems with the sportfishing industry by targeting non-billfish species. If this happens, it is recommended that data collection should be continued in such a way to permit determination of the potential interaction between surface and longline fisheries.

6. ACKNOWLEDGMENTS

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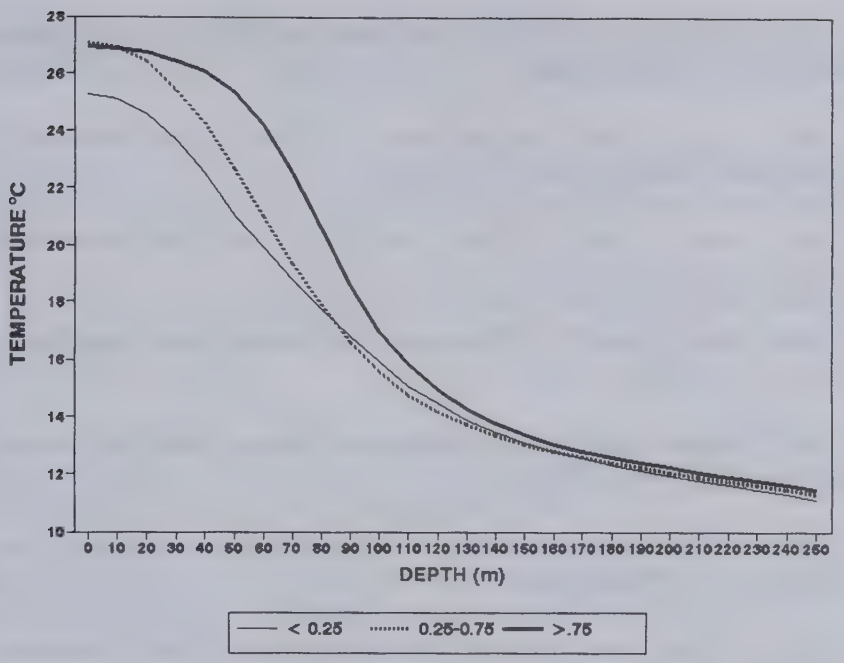

Figure 7. Average temperature profiles associated with yellowfin tuna catch rates in the interaction zone (Mexican longline fishery).

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INFLUENCE OF PURSE SEINE FISHERY ON LONGLINE FISHERY FOR YELLOWFIN TUNA (*THUNNUS ALBACARES*) IN THE WESTERN INDIAN OCEAN

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ABSTRACT

The influence of the industrial purse seine fishery on the industrial longline fishery in the western Indian Ocean is examined. The two basic analyses carried out include a study of the temporal-spatial fluctuations of CPUE and size of yellowfin tuna caught by the longline fishery before and after the start of the purse seine fishery in 1982 and a study of the relationship of the longline CPUE and the purse seine catch. The results of these studies suggest that the influence of the purse seine fishery on the longline fishery is only moderate in areas of intensive purse seine fishing and that there appears to be no apparent influence of the purse seine fishery on the longline fishery outside the immediate area of intensive purse seine fishing.

1. INTRODUCTION

Large-scale commercial purse seine fishing in the Indian Ocean was initiated by French purse seine vessels which began operating in the western Indian Ocean in 1982. In 1983, Mauritius and Japan also began purse seining in the area. During 1982 and 1983, operations were on an exploratory basis and the total catch was about 4,500 mt and 24,000 mt for the two years, respectively. The purse seine catch made up 2% and 9% of the total tuna catch for FAO Area F51 (Figure 1). Due to the successful fishing trials in 1982-83, Spain, Ivory Coast, Panama and United Kingdom joined the purse seine fishery in 1984. Other countries (Cayman Islands, Malta, USSR and Seychelles) joined the fishery in more recent years. The total purse seine tuna catch increased significantly to 103,00 mt in 1984 representing about 32% of the total tuna catch in Area 51. The catch has continued to increase and reached 291,000 mt in 1992; the catch represented about 40% of the catch in Area 51. Among the purse seine fishing countries operating in the western Indian Ocean, France and Spain have the two dominant purse seine fleets in the area.

The species composition of the purse seine catch from 1984-92 was 52% skipjack, 43% yellowfin, 4% bigeye, and 1% other species. Among the tuna species, the yellowfin tuna is the most important commercial tuna species. The yellowfin is commonly exploited by purse seine and longline gear; the latter by the longline fleets of Korea, Japan, and Taiwan. The areas of fishing for yellowfin in the Indian Ocean are shown in Figure 2.

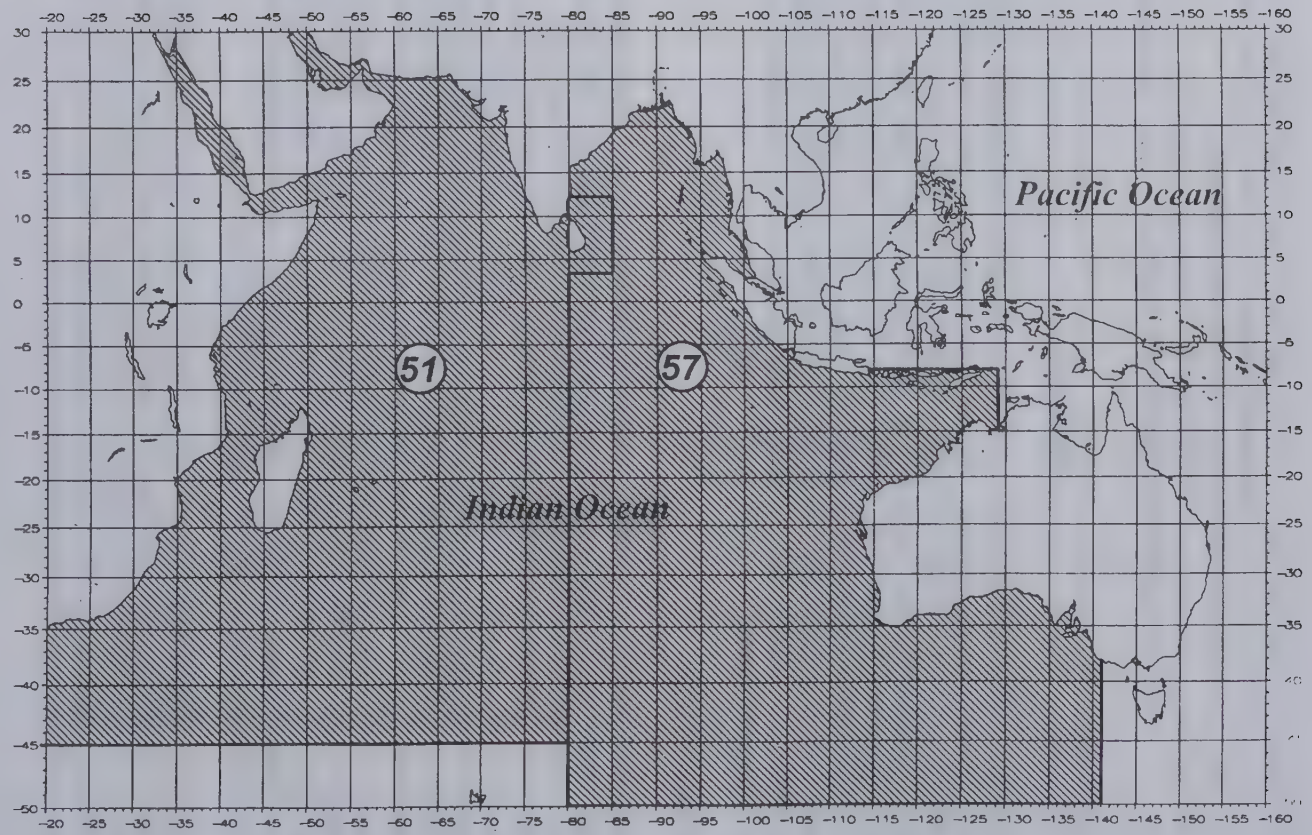


Figure 1. Area of competence of Indo-Pacific Tuna Development and Management Program in terms of FAO statistical areas.

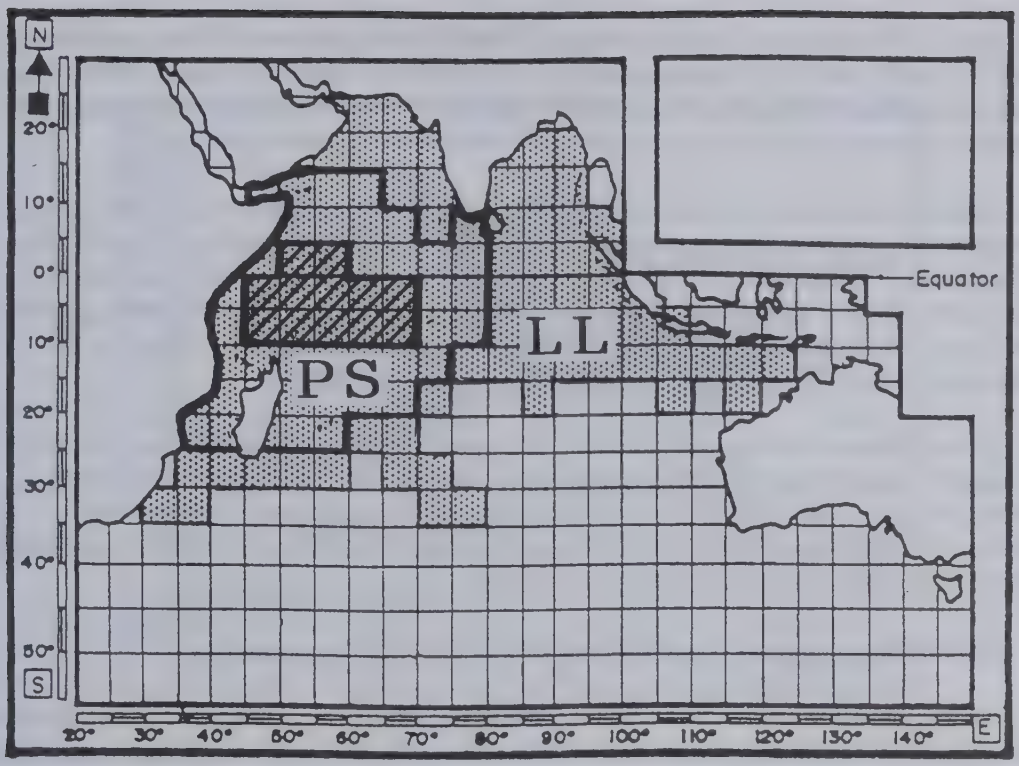


Figure 2. Yellowfin tuna longline and purse seine fishing grounds in the Indian Ocean. Shaded zone is the longline ground defined as 5° x 5° areas producing an annual average of more than 0.5 fish/1000 hooks during 1983-91. The purse seine ground is surrounded by thick borders, defined as the 5° x 5° areas where purse seine fishing was conducted by vessels from France or Spain at least once during 1983-91. The diagonally hatched area represents the major (heavy) purse seine fishing ground, i.e., producing more than 1.5 mt per year per 5° square.

With the introduction of purse seining in the western Indian Ocean, it was only a matter of time that the longline fishing nations would start to become concerned with the possibility of the purse seine operation impacting the longline fishery. It is also only a matter of course that artisanal fisheries of developing nations in the region (Maldives, Sri Lanka, Pakistan and other nations in the western Indian Ocean) would also start to worry about the possible impact of purse seining on their coastal tuna fisheries. Basically, there are six types of fisheries interactions to be considered, i.e., purse seine ⇄ longline, purse seine ⇄ artisanal fisheries, artisanal fisheries ⇄ longline. Based on previous studies, it appears that the purse seine ⇄ longline interaction is considered the most serious. In this paper, the descriptive analyses provided are based on fisheries information accumulated from the purse seine and longline fisheries.

In conducting fisheries interaction studies, the stock structure needs to be initially defined. This paper assumes the yellowfin population in the Indian Ocean is made up of two major stocks (west and east) and two possible minor stocks (far west and far east or Pacific stock); the assumed stock structure is shown in Figure 3. The stock structure is based upon (a) past studies of stock structure by Hirano and Tagawa (1956), Kurogane and

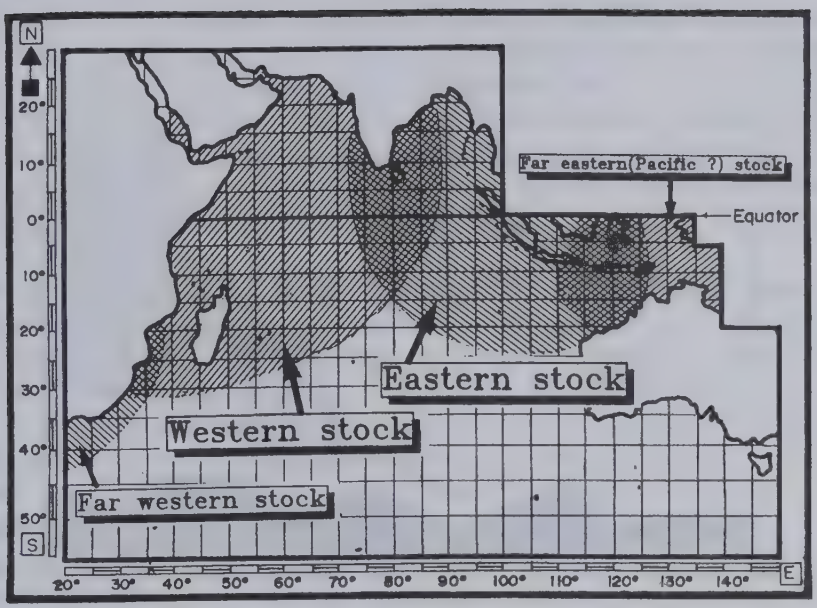
Hiyama (1958), Mimura (1958), Kurogane (1960), Morita and Koto (1970), and Nishida (1991), and (b) results of tagging experiments in the Indian Ocean by Yano (1990), Cayre and Ramcharrun (1990), and Waheed and Anderson (1993). The present study concerns mainly the western yellowfin stock.

Figure 4 shows the trend of the annual catch of yellowfin landed by the purse seine, longline, and artisanal fisheries from 1972 to 1992; the data are based upon statistics for FAO Area 51 which were summarized by Nishida (1993). The yellowfin catch by the purse seine fishery is about 2-5 times that of the longline fishery. The yellowfin catch by the longline fishery was more or less constant ranging from 17,000-38,000 mt for the period covering before and after the start of the purse seine fishery.

Under the above mentioned situation, this paper attempts to investigate the possible impact of the purse seine fishery on the longline fishery for the western Indian Ocean yellowfin stock. Past research on fisheries interactions on yellowfin are reviewed, followed by the present study which involves descriptive (spatial and temporal) analyses of fisheries statistics (catch, CPUE, and size of fish).

2. REVIEW

Table 1 summarizes previous studies relating to fisheries interactions of yellowfin tuna in the Indian Ocean; these studies are classified into qualitative and quantitative analyses. Regarding the influence of the purse seine fishery on the longline fishery, all of the studies predicted existence of a moderate impact of the purse seine fishery on the longline fishery. Marsac and Hallier (1987) and Bertignac (1993) showed the impact by conducting Ricker-type simulation analyses. In these yield per recruit (Y/R) simulation studies, the impacts of one fishery on the other were done by changing fishing mortality (F). Both papers concluded that the purse seine fishery moderately impacted the longline fishery. Review papers by Marcille (1986) and Suzuki (1987) also predicted effects of purse seine over longline by referring to similar cases in the Atlantic and Pacific Oceans, respectively. Nishida (1988) found local impacts of purse seine on longline in areas of overlapping fisheries. Nishida (1988) also found a positive impact (increases in purse seine catch accompanied by increase in longline CPUE) in the surrounding waters of the operational areas of purse seine and longline. It should be noted here that Nishida (1988) only had four years of data after the start of the purse seine fishery; thus, the long term effect needs to be re-investigated. Tsuji (1994) made similar comments about local impacts of purse seine on longline for the yellowfin fisheries in the western Pacific Ocean. Bertignac (1993) recommended that spatially concerned models should be developed since his interaction study was not spatially aggregated and thus may have masked the true situation. The present descriptive analyses of spatial and temporal changes in CPUE and size frequency data were carried out with consideration of past studies. It is the intent of this study to determine why the predicted impacts of the purse seine fishery on the longline fishery are not apparent in the collected fisheries statistics.



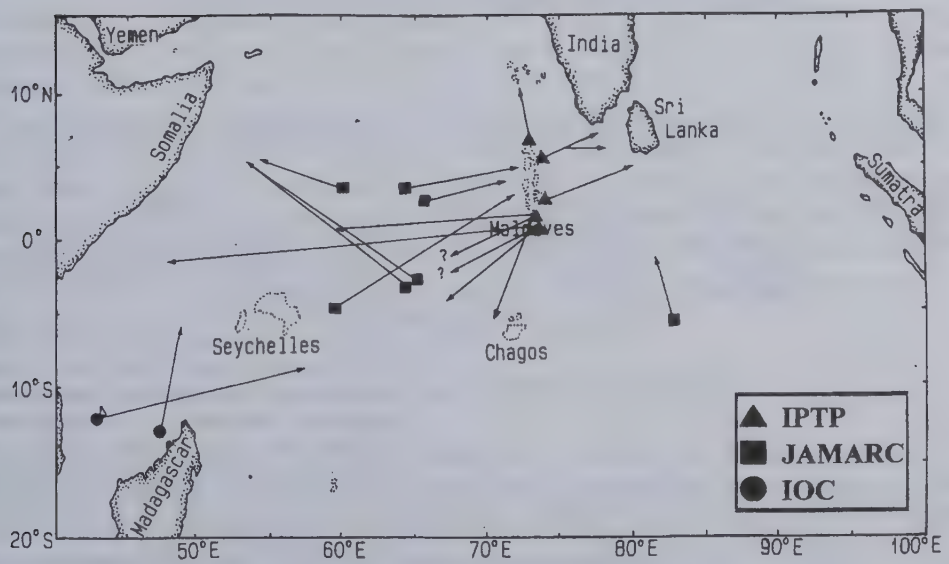


Figure 3. Assumed stock structure (upper panel) and results of tagging experiments (lower panel). IPTP=Indo-Pacific Tuna Programme, JAMARC=Japan Marine Fishery Resources Research Center, IOC=Indian Ocean Commission.

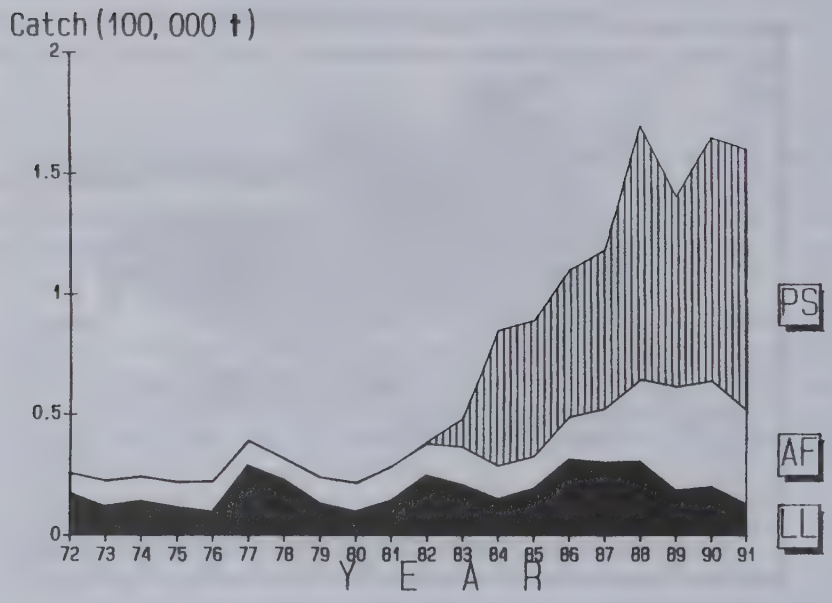


Figure 4. Annual yellowfin tuna catch trend by longline (LL), purse seine (PS) and artisanal (AF) fisheries in the western Indian Ocean (FAO statistical area F51).

Table 1. Papers and reports of fisheries interactions for yellowfin tuna in the Indian Ocean.

Type of Analysis	Method	Author	Year	Conclusion
Quantitative	Ricker-type simulation model for Y/R	Marsac and Hallier	1987	Increasing purse seine catches generate a moderate negative effect on longline and no effect on artisanal fisheries
		Bertignac	1993	Reduction of purse seine effort could result in 20-30% increase of longline catch, but such impacts were not observed. If effort by purse seine (log) is reduced, purse seine (free), longline and artisanal catches could increase 15-20%. Oman-type fisheries impact purse seine and longline.
Qualitative	Review	Marcille	1986	Purse seine could reduce longline catch by 30-50% over next few years.
		Suzuki	1987	Total yellowfin catch should increase by developing purse seine fishery and reduced longline catch.
	Analysis of CPUE/size	Nishida	1988	Purse seine impacts longline within same fishing grounds. No conclusion about interaction between purse seine and artisanal fisheries.

3. DATA AND ANALYSES

The available historical fisheries data (catch, effort, and fish size) from the Indo-Pacific Tuna Development and Management Programme (IPTP) and the National Research Institute of Far Seas Fisheries (NRIFSF) were used in this study of spatial and temporal changes in CPUE and size frequency distribution of yellowfin tuna caught on longline gear before and after the start of the purse seine fishery in the western Indian Ocean. In addition, the relationship between CPUE of longline-caught yellowfin and the purse seine catch of yellowfin were investigated for possible evidence of interaction between fisheries.

In these analyses some caution needs to be exercised in interpreting the results, i.e., a decrease in CPUE of the longline-caught yellowfin or a change in size frequency distribution do not necessarily imply impacts of purse seine on longline. Other factors such as environmental conditions, presence of strong cohorts, availability of fish, etc. may be responsible for the changes. However, if consistent patterns of changes occur with different analyses, the possibility of a fishery interaction is strengthened.

3.1 CPUE (long-term influence)

3.1.1 Spatial Analyses

In order to examine the wide-spread effects of the purse seine fishery on the longline fishery spatial analyses were carried out using 5^{o} x 5^{o} areal units. These analyses were performed by comparing distributional maps of annual average CPUE of longline-caught yellowfin for the periods before and after the start of the purse seine fishery in 1983 and by examining distribution maps for differences in CPUE between these two periods. Figure 5 (revised from data provided by Nishida, 1988) shows the short term situation (four years before and after the start of purse seining), while Figure 6 shows the long term case (eight years before and after the start of purse seining). Both the short and long term situations show decreases in CPUE for a majority of the 5 degree squares in and around the major purse seine fishing grounds. On the other hand, increases in CPUE are observed in a majority of the 5 degree squares in the waters surrounding the intensive purse seine fishing area.

3.1.2 Trend of Annual CPUE (entire purse seine fishing ground)

The historical annual CPUE data of yellowfin tuna caught by the longline fleets of Korea, Japan, and Taiwan in the purse seine fishing grounds have been compiled. Trends of CPUE from 1954 to 1991 are shown in Figure 7 (top), while those for 1975-91 are shown enlarged in Figure 7 (bottom). The purse seine fishing ground is defined as the 5^{o} x 5^{o} area where at least one purse seine operation was conducted during 1983-91 (Figure 2).

Based on Figure 7, the average CPUE of longline-caught yellowfin decreased drastically from about 90 fish/1,000 hooks at its peak in the mid-1950s to less than 10 fish/1,000 hooks after 1973. The trend in CPUE for the period before and after the start of the purse seine fishery (Figure 7, bottom panel) show relatively low level catch rates which ranged from 3 to 9 fish/1,000 hooks; an exception occurred in 1977-78 when the catch rate exceeded 13 fish/1,000 hooks. Patterns of the CPUE trends for Korea, Japan,

and Taiwan are almost identical; however, the CPUE values of the Taiwan fleet are lower than those of Korea and Japan. This difference is probably because Taiwan targets mainly albacore; the fishing efficiency for yellowfin in this case is lower than the other two fleets.

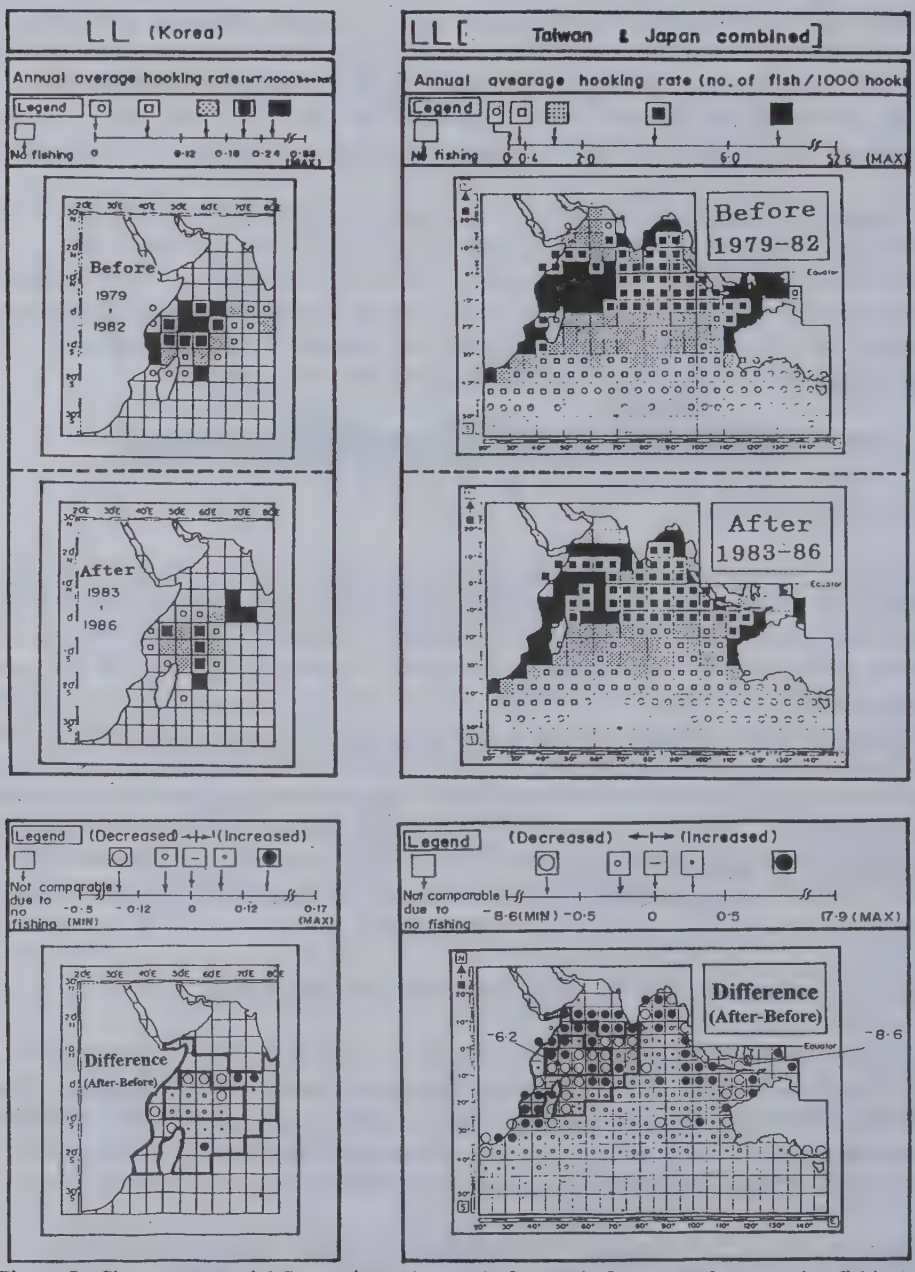


Figure 5. Short term spatial fluctuations (4 years before and after start of purse seine fishing) of longline CPUE for Korea (left) and Japan and Taiwan combined (right). The top 5° x 5° maps show CPUE distribution before purse seine fishing started in 1983. The middle maps show CPUEs after purse seining started. The bottom maps show the differences between these two periods.

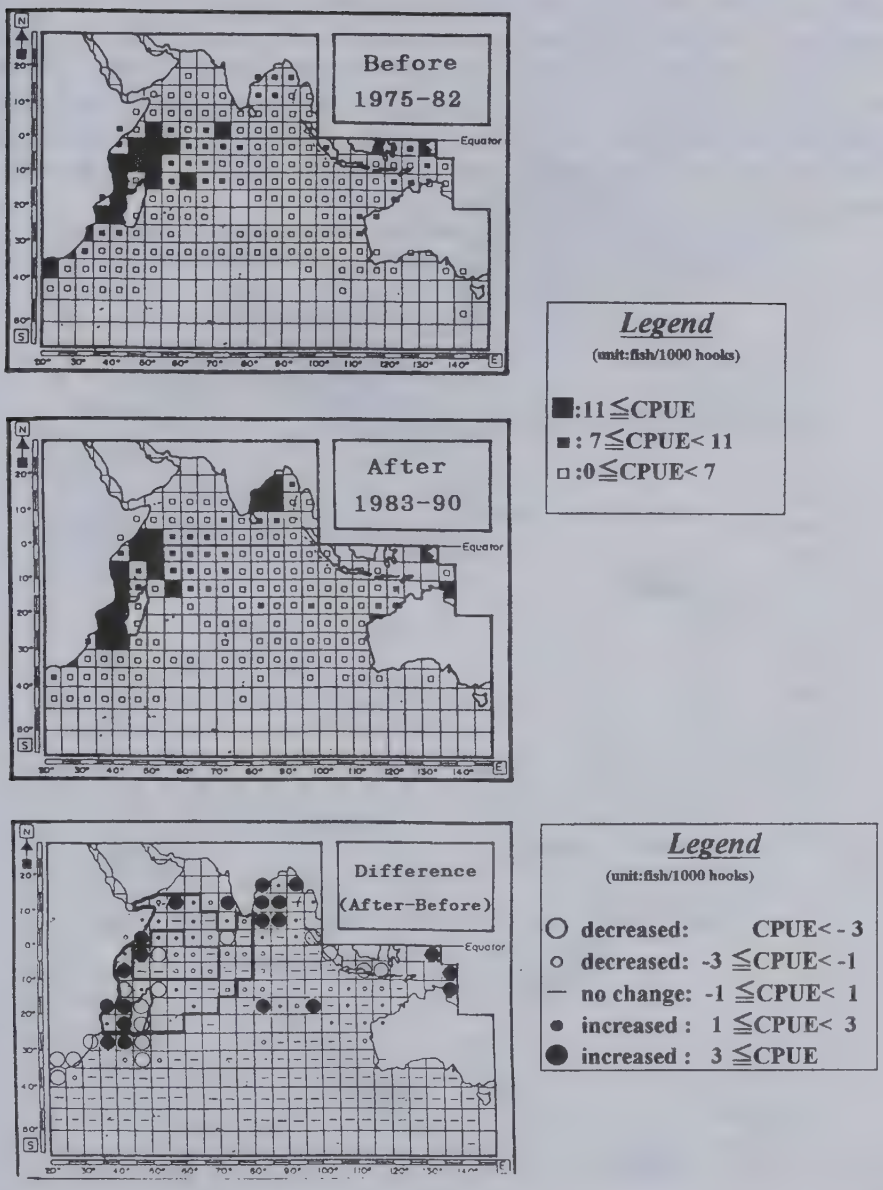


Figure 6. Long term spatial fluctuations (8 years before and after start of purse seine fishing) of longline CPUE for Korea (left) and Japan and Taiwan combined (right). The top 5° x 5° maps show CPUE distribution before purse seine fishing started in 1983. The middle maps show CPUEs after purse seining started. The bottom maps show the differences between these two periods.

3.1.3 Annual CPUE Trend (intensive purse seine fishing ground)

As observed in the spatial analysis, the CPUE of the longline fishery decreased in a majority of the 5 degree squares in the major purse seine fishing grounds after the start of the purse seine fishery. The major purse seine fishing ground is defined as the 5° x 5° square areas which produced more than 4,500 mt of yellowfin per year (combined French

and Spanish purse seine catch). Figure 8 shows the annual average CPUE of the combined Korea, Japan, and Taiwan longline catch of yellowfin for the period 1955-91 (Figure 8, top panel); the period from 1975-91 is shown enlarged (Figure 8, bottom panel). The time series covering recent years (Figure 8, bottom panel) indicates a moderate decreasing trend after the start of purse seining in 1983. The overall average CPUE before the start of purse seining (1975-82) was 4.7 fish/1,000 hooks, while the average CPUE after the start of purse seining was 2.9 fish/1,000 hooks; a decline of 36%.

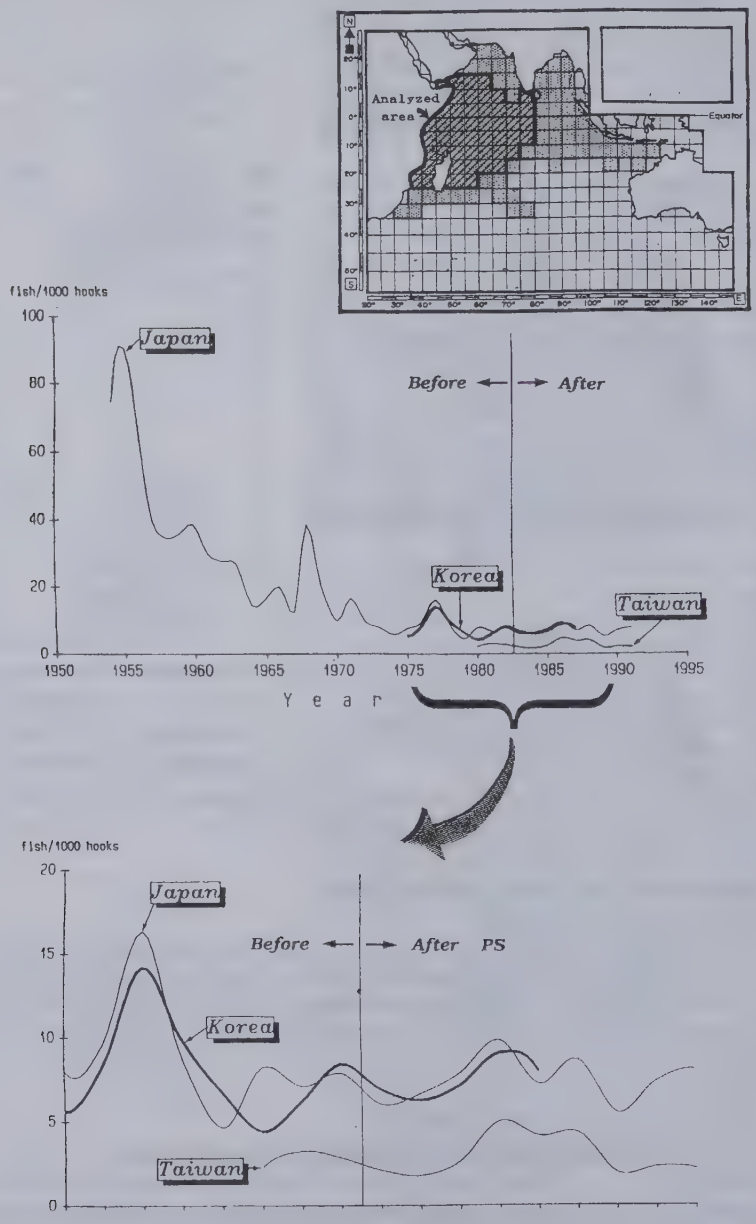


Figure 7. Trends of annual longline CPUE for Korea, Japan and Taiwan for 1954-91 (upper panel), and enlarged plot for 1975-91 (covering 8-9 years before and after purse seining started), for the whole purse seine fishing ground (lower panel).

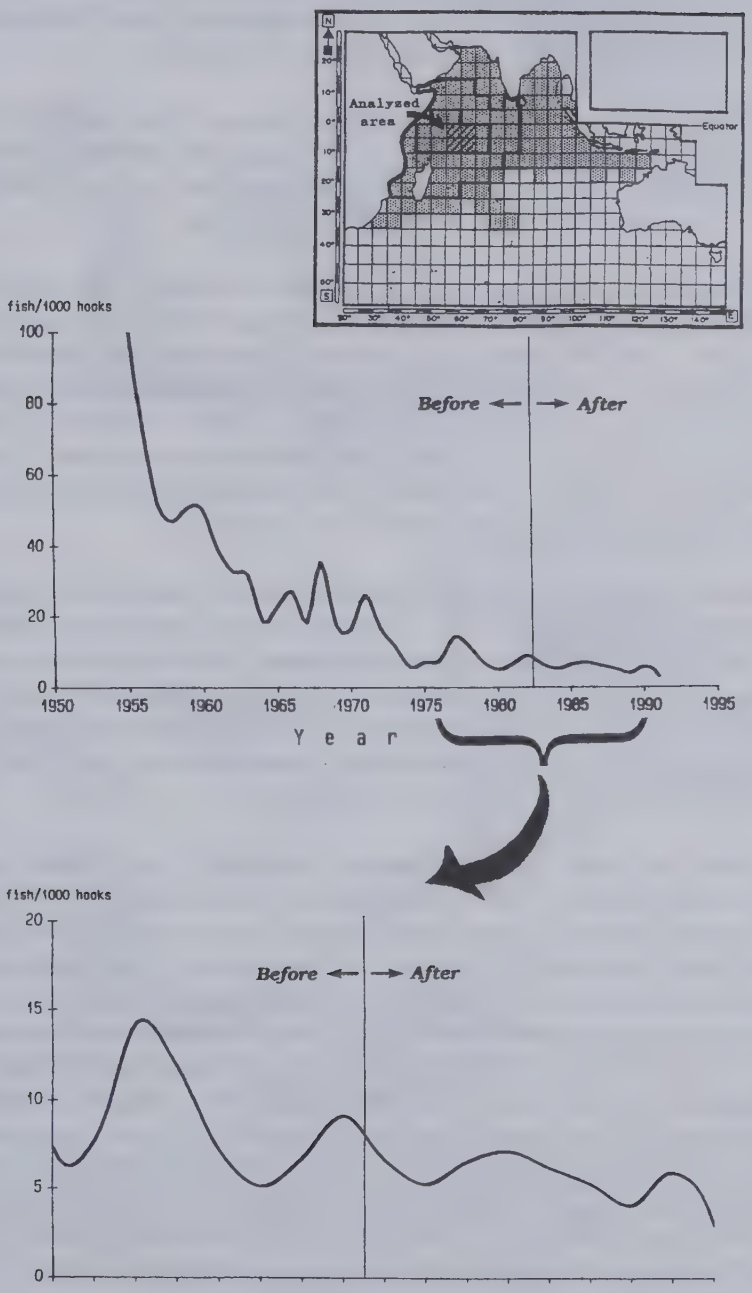


Figure 8. Trends of annual longline CPUE for 1955-91 (upper panel), and enlarged plot for 1975-91 (covering 8-9 years before and after purse seining started), for the heavy purse seine fishing ground (lower panel).

3.2 Size Frequency Distribution (long term influence)

The CPUE analyses showed that there were almost no changes in CPUE of longline-caught yellowfin from the wider regions of the purse seine fishing grounds; however, there appeared to be moderate decreases in CPUE in the major purse seine fishing area. Similar analyses were carried out to assess the changes in size of yellowfin.

The data on size of fish from the Japanese and Taiwanese fleets were combined and standardized into 2-cm class intervals and by 5° x 5° area; the data were then converted into percent frequency distributions. In the analyses, eight years of data before and after the start of purse seining (1975-82 and 1983-90) were utilized.

During processing of the Japanese size data, some of the data were suspected to have been measured originally by 5 cm or 10 cm class intervals instead of the 1 cm or 2 cm class intervals requested. This possibility was suggested by the sharp pulses noted in the size frequency distributions. It is possible that some Japanese longline fishermen measure size of fish roughly by 5 cm or 10 cm intervals because it is easier to estimate fish into these wider class intervals, especially during rough weather conditions and under busy working conditions (Shiohama, NRIFSF, pers. comm.). This problem was corrected by smoothing frequencies by taking a moving average of five class intervals.

The purse seine size data were also processed in the same way as the longline size data in order to allow for proper comparisons. In the purse seine fishery large yellowfin (80-160 cm) are caught mainly from free-swimming schools, while smaller size yellowfin (20-80 cm) are caught mainly from log-associated schools. In the longline fishery the catch mainly consists of large yellowfin (80-160 cm); thus, 80-150 cm yellowfin are commonly exploited by purse seiners fishing free-swimming schools and longliners, while purse seiners fishing log-associated schools catch small yellowfin.

Figure 9 shows size frequency distributions of yellowfin for the longline fishery (before and after the start of purse seine fishing) and the purse seine fishery for the entire purse seine fishing ground (Figure 9, upper panel) and the most intensively fished purse seine area. For the broad purse seine fishing area, the size frequency distributions for the longline fishery before and after the start of purse seining appear to be similar. The average size of yellowfin landed was 116 cm for the period prior to the start of purse seining and 120 cm for the period after the start of purse seining. On the other hand, for the area of intense purse seine fishing, the modal group for the longline fishery after the start of purse seining is larger than for the period prior to the start of purse seining. The average size of yellowfin was 122 cm and 110 cm for the two periods, respectively. For the purse seine fishery, the size of yellowfin for the extended fishing grounds and the intensively fished areas were similar. There appear to be two distinct modal groups with a large mode of small-size fish around 50 cm for log-associated schools and a smaller modal group of larger fish at 125 cm for free-swimming schools.

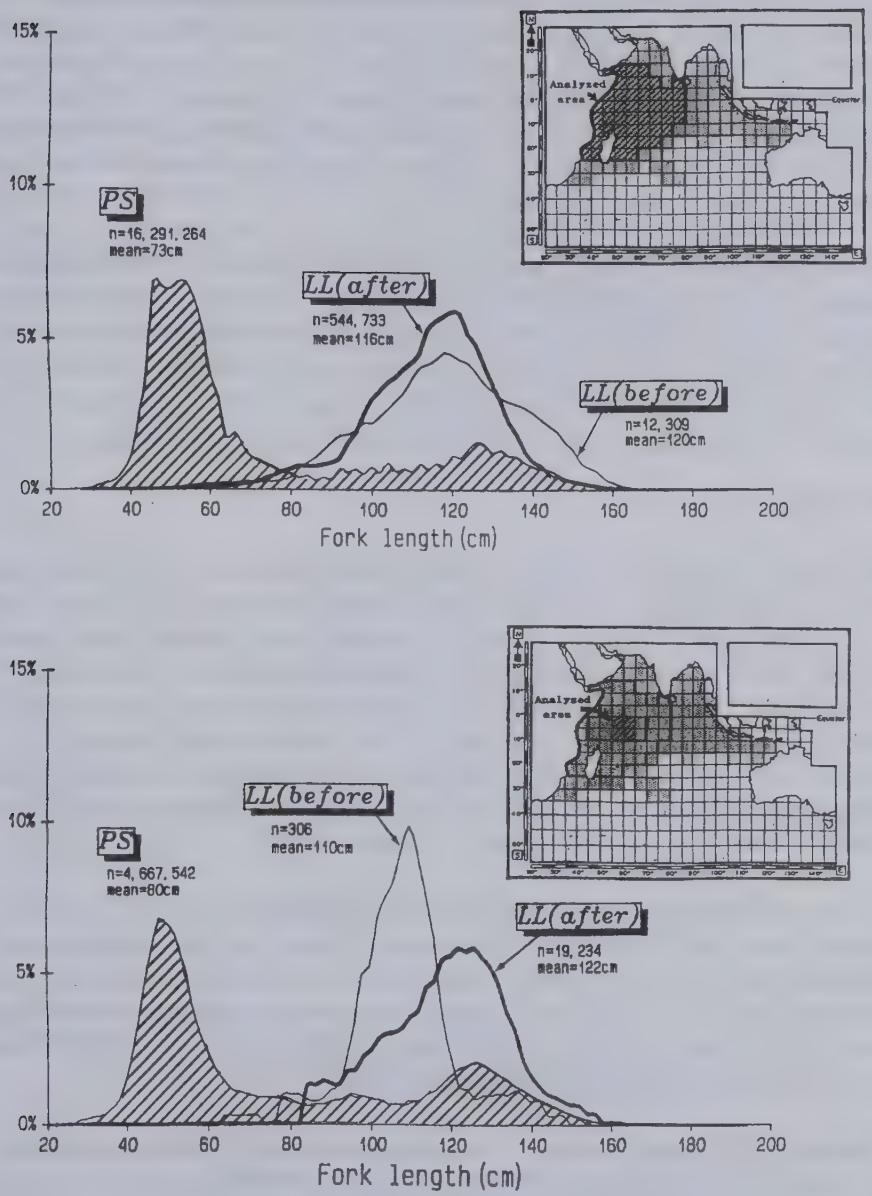


Figure 9. Comparison of size frequency distribution of yellowfin tuna caught with longline gear before (1975-82) and after (1983-90) the start of purse seine fishing, and purse-seine caught yellowfin from the entire (upper panel) and heavy (lower panel) purse seine ground.

3.3 Relationship between CPUE of the Longline Fishery and Purse Seine Catch (immediate influence)

For the final analysis, a relationship between CPUE of the longline fishery and the purse seine catch of yellowfin was investigated. The analysis was conducted by plotting

monthly CPUE (fish/1,000 hooks) of the longline fishery and purse seine catch of yellowfin by 5° x 5° degree squares. For the longline data the monthly average CPUE for the fleets of Korea, Japan, and Taiwan were combined, while the purse seine data consisted of the combined French and Spanish purse seine fleet for the entire area of operation. Figure 10 (upper panel) shows the basic scatter diagram for the period 1982-91. It clearly shows that all plots are located within the diagonal border made by the two outer points. This implies that the relationship between CPUE of the longline fishery and the catch of the purse seine fishery are inversely related.

The scatter plots of the purse seine catch are classified into four clusters (Figure 10, bottom panel). Cluster A includes 90% of the total points, while the remaining 10% is distributed among the other three clusters. Hence, the relationship between CPUE of the longline fishery and the catch of the purse seine fishery is dominated by Cluster A. This dominance implies there is no obvious relationship between CPUE of the longline fishery and the catch of the purse seine fishery; at least for the ranges encountered.

4. DISCUSSION

Basic descriptive analyses of spatial and temporal fluctuations of CPUE of the longline fishery (all ages pooled) and size frequency distributions in response to the catch of the purse seine fishery were carried out to examine possible impacts of one fishery on the other. In this type of analysis, careful interpretations of changes of CPUE and size frequencies must be examined. This is because factors other than the impact of one fishery on the other may be responsible for the changes. The factors include changes in environmental conditions, presence of strong cohorts, and availability of fish. If consistent changes are observed based on different types of analyses, it is possible to provide evidence of the impact of the purse seine fishery on the longline fishery.

The results of this study showed that the CPUE of the longline fishery remained relatively stable over the broad area of the purse seine fishery for the period prior to and after the start of the purse seine fishery. When data for the heavily fished purse seine area were examined the longline CPUE showed a modest decrease. Table 2 summarises the analyses of CPUE trends. It clearly demonstrates the differences between the extended purse seine fishing area and the area of intensive fishing.

The question of why there is only a moderate decrease in CPUE of the longline fishery despite the large purse seine catch will be discussed in the following sections for the (a) long-term situation, and (b) the immediate situation.

Long-term situation

In the case of long term influence, the reason for the moderate decrease in CPUE of longline-caught yellowfin in the presence of large catches of yellowfin by the purse seine fishery may be due to the existence of a cryptic biomass. The longline gear is deployed from 50-300 m water depth depending upon the species targeted. Images of tuna have been reported at depths of 500-2,000 m water depth (Yamada, 1991; Kawamura, 1994). Since tunas range vertically beyond the depth range of the longline gear and horizontally beyond the range of the tuna fishery, a portion of the yellowfin resource is assumed to be out of

reach of the longline fishery. This portion of the resource is defined as the cryptic biomass. Fonteneau (1994) provides a detailed discussion of cryptic biomass and its relationship to the resource.

In the western Indian Ocean, the CPUE of adult yellowfin caught by the longline fishery is currently 20-25% of the level achieved in the 1950s when the longline fishery first started in the Indian Ocean. Hence, at present, the adult population of yellowfin tuna is apparently at a low level as indicated by the low CPUE values. If one accepts the concept of cryptic biomass, the true population size of yellowfin is probably much larger than predicted based on the level of CPUE. This is again the major reason why the CPUE of the longline fishery is not influenced by the large catch of yellowfin by the purse seine fishery. This may describe the situation as predicted by the simulation studies undertaken by Marsac and Hallier (1987) and Bertignac (1993).

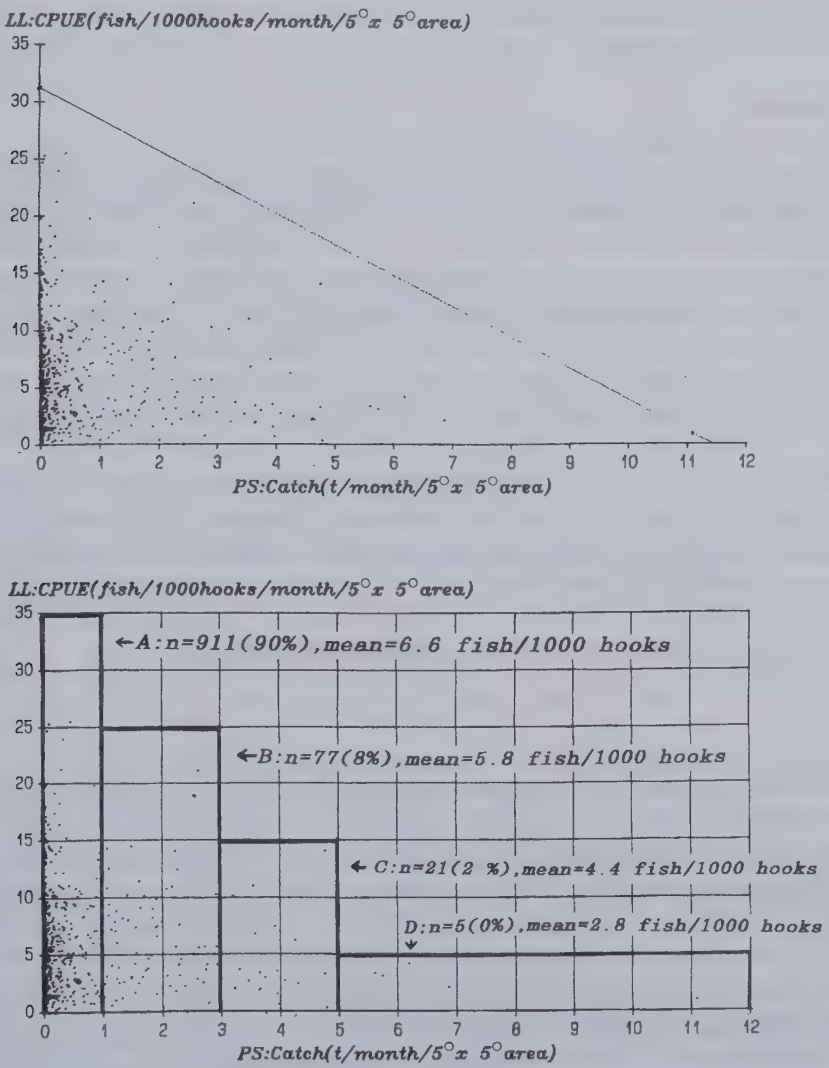


Figure 10. Upper panel, original scatter plots of longline CPUE vs. purse seine catch. Lower panel, four clusters of these scatter plots by purse seine catch intervals.

Table 2. Summary of longline CPUE analyses.

Area Analysed	Longline	Time Scale	B: Average Longline CPUE Before Purse Seine, 1975-82 fish/1000 hooks)	A: Average Longline CPUE After Purse Seine, 1983-91 (fish/1000 hooks)	Rate of Change (%) from B to A = (A-B)*100/B
Whole PS fishing ground	Korea	Annual	8.2	7.5	-9%
	Japan	Annual	8.2	7.6	-7
	Taiwan	Annual	2.8	3.0	-7
Heavy PS fishing ground	Average	Annual	4.7	2.9	-38
		Quarterly	11.7	6.6	-44
		Quarterly	12.2	10.6	-13
		Quarterly	2.7	4.7	+74
		Quarterly	11.0	4.5	-59

Immediate situation

In case of the immediate situation, Figure 10 provides some interesting insights for the reasons why the moderate increases in CPUE of the longline fishery in the area of intense purse seining is not reflected outside this area. As shown in Figure 10 (bottom panel), each cluster has its own upper limit of CPUE of the longline fishery. Cluster A includes about 90% of the total data points and within its range it is not clear that the purse seine catch affects the longline catch of yellowfin; this may be due to the wide range of the CPUE of the longline fishery. On the other hand, in other clusters (B-D) there are clear upper limits of CPUE. Thus, it is obvious that the catch of the purse seine fishery affects the longline fishery when the purse seine catch exceeds 1 ton/month/5° x 5° area. However, since there are only 5% of the data points in these three clusters, it can be generally concluded that there are no serious immediate influences of the purse seine fishery impacting the longline fishery; at least at current catch levels. This immediate impact is mainly caused by the purse seine catch of the larger size yellowfin (80-160 cm) since this size group is also exploited by the longline fishery. However, this influence may be masked by the existence of the cryptic biomass discussed earlier.

Further studies

There is a need to investigate the cryptic biomass of the yellowfin population in the western Indian Ocean by conducting tagging experiments using archival and/or sonic tags. Data obtained from these experiments will help elucidate the time and depth distribution of adult yellowfin tuna and also elucidate the proportion the cryptic biomass that make up the total yellowfin population in the region. Additionally, it will be necessary to estimate the unbiased CPUE of the longline fishery by correcting for the cryptic biomass. It may be desirable to cross-check the accuracy of the corrected CPUEs by carrying out simulation studies. The General Linear Model (GLM) analyses may be effective in assessing the influence of the purse seine fishery on the longline fishery quantitatively. This examination can be conducted by the following model:

Longline (CPUE) = (mean) + year + season + area + purse seine catch + environmental factors

where the area term includes the heavily purse seine fished area as well as the extended fishing area.

5. ACKNOWLEDGMENTS

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STUDIES ON THE POPULATION STRUCTURE OF SKIPJACK TUNA, *KATSUWONUS PELAMIS*, IN THE CENTRAL AND EASTERN PACIFIC OCEAN: SIGNS OF INTERACTION POTENTIAL USING ENVIRONMENTAL DATA

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ABSTRACT

In the past decade, research on the population dynamics of skipjack tuna (*Katsuwonus pelamis*) has shifted from questions on stock productivity to concerns about interaction among fisheries, including the intense and growing fisheries in the eastern Pacific Ocean (EPO), where few if any skipjack spawn. In this region market pressure will limit the catch of yellowfin tuna (*Thunnus albacares*) associated with dolphins, hence, fishing effort on the skipjack resources is likely to grow. The impact of increased harvest is difficult to assess because the mixing of fish between areas is poorly understood.

In this paper, the population structure of skipjack and the potential for fishery interaction between the EPO and Hawaii, were evaluated. The main objective of this study was to present an alternative method of studying the stock structure and interaction potential of skipjack tuna in the Pacific Ocean. Previously, the chemical composition of skipjack otoliths was analysed using electron-beam microprobe technology. Chemical analyses of different growth zones on the otolith structure contain information on the potential origins of skipjack caught in different regions. However, the usefulness of the results for fisheries management purposes remains open to interpretation. Analyses of skipjack population structure using fishery-generated length-frequency data allowed tests of hypotheses on skipjack population structure through models of seasonal recruitment patterns. The recruitment patterns indicated, however, that the majority of the catch in the central and eastern tropical Pacific originated from broods spawned at different times of the year. The majority of skipjack production for the respective fisheries is based on a single stock that spawns over an extended period in the central Pacific. The seasonal recruitment pattern observed may be due to an extended spawning season with eastward migration of the larval and juvenile stages following seasonal extensions of the equatorial water masses. Alternatively, relatively distinct stocks with different peak spawning periods may explain the observed seasonality of brood events. To examine these recruitment hypotheses, oceanographic data were compiled to show seasonal habitat shifts. I believe that the underlying environmental variability both within and between years plays an important role in the movement of skipjack, and consequently, interaction potential between fisheries in different regions.

1. INTRODUCTION

The world-wide landings of tuna have doubled in each decade since 1950 and exceeded 2 million mt per year in the 1980s. Skipjack tuna (*Katsuwonus pelamis*, hereinafter

referred to as skipjack) have made up a significant and growing share of the total tuna harvest. In the 1960s, skipjack represented about 25% of the world tuna landings; in recent years skipjack comprise over 40% of the total (FAO, 1975; 1991). The skipjack tuna fisheries operating in the Pacific Ocean are primarily responsible for these increases, taking more than 80% of the skipjack harvest.

Early stock assessments of skipjack dealt with issues of maximum sustainable yield and optimal fishing strategies on a yield-per-recruit basis (e.g., Schaefer, 1954; Joseph and Calkins, 1969). As more information was collected and analysed it became apparent that skipjack were widely distributed and that skipjack fisheries in many areas depended to a large extent upon immigration of fish from elsewhere. This realisation has drawn attention to the problem of understanding the skipjack population structure. For example, regarding skipjack assessments the IATTC (1991) stated that:

> ". . . [stock production methods] are not applicable unless the fish in question belongs to a discrete population, *i.e.* there is relatively little interchange between the fish in the area under consideration, in this case the eastern Pacific Ocean, and those in other areas where the species in question is exploited, or the exchange rates among subpopulations are known. . . . In the absence of definition of the population being exploited, production modeling is of little or no value for skipjack in the eastern Pacific fishery."

Reliable fisheries management may not be possible without understanding the geographic range of the reproducing segment of the stock. Once the geographic distribution of the stock(s) and movements are better understood, a set of hypotheses on biological productivity can be evaluated.

In addition to biological stock assessment issues related to overall productivity and resilience to fishing, questions regarding the effect of fisheries within national jurisdictions or areas on fishing conditions in other areas are currently being asked. This problem is commonly referred to as a form of *fishery interaction*. Because much of the skipjack now come under jurisdiction of coastal states declaring 200 mile economic zones, the potential for interactions among different fisheries has increased. Assessment of interaction requires quantification of the amount of exchange and/or interdependence of fish between areas. Knowledge of the spatio-temporal aspects of skipjack life history stages for the stock or stocks in question is also required.

One approach to evaluate the spatio-temporal patterns of skipjack life history stages is to examine age or size-specific recruitment to different areas and months. Ianelli (1993) examined this in detail and found that skipjack recruitment in the eastern Pacific Ocean (EPO) and Hawaii were variable yet revealed an underlying seasonal pattern (Figure 1). The observed recruitment patterns in these areas may be due to seasonal spawning that occurs locally or in adjacent waters or to seasonal oceanographic events superimposed on a stock that spawns in the central Pacific with relatively uniform intensity during all months of the year.

An analysis of the physical environment of skipjack was needed to examine these possibilities. The ideal way to describe the spatial dynamics of skipjack population

behaviour would be to have direct observations on egg, larvae, and juvenile abundance over a broad geographic region and long time period. Such data do not exist and we rely on synoptic studies such as Nishikawa et al. (1985) and Argue et al. (1983) for information on the general distribution of skipjack in early life stages. It is reasonable to propose a relationship between skipjack larval distribution and oceanographic conditions based on these and other studies. As water temperature is the most widely available type of oceanographic data, I used it as a proxy for examining the dynamics of skipjack spawning and larval-development habitat.

In this paper, I examine oceanographic data to evaluate the relationship between the physical environment and observed skipjack recruitment patterns. The analysis is organised in two parts. First, oceanographic data on mean monthly conditions in an average year are compiled. This type of information is commonly referred to as a "climatology." Second, a time series of oceanographic data was used to examine interannual variation in sea surface temperature. The time series data included monthly mean sea surface temperatures for the period 1955-89 while the climatology data contained both sea surface temperature and temperature-at-depth data. In both cases, the physical variables were qualitatively compared with the recruitment patterns from the fishery data.

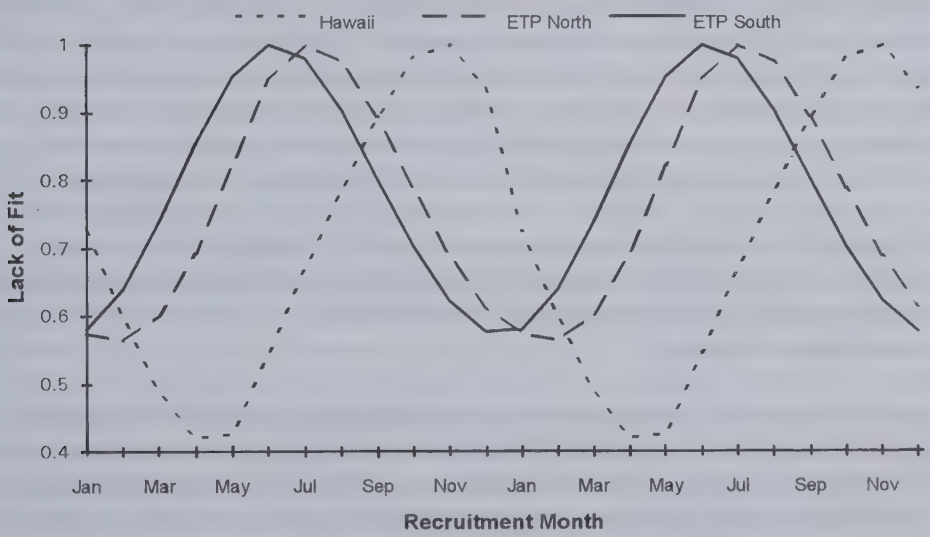

Figure 1. Lack of fit profile to fishery size composition data for three areas showing differences in patterns of cohorts between the central and eastern Pacific. This figure indicates that the model fit the data best with recruitment of the first age class (defined to have a mean length of 40 cm) occurring from March to June in Hawaii and from November to December in the EPO. For further details see Ianelli (1993).

2. SEASONAL PATTERNS IN THE PHYSICAL ENVIRONMENT

This section examines oceanographic conditions on a seasonal basis and makes inferences on the spawning/larval habitat of skipjack. The goal is to determine if the

dynamics of the physical habitat are consistent with the recruitment patterns observed and to gain insight on the role these dynamics may have on the distribution and movement of skipjack. Given the seasonal recruitment patterns in the EPO and Hawaii presented above, several propositions can be constructed about the relationship between regional spawning activity and movement potential between the regions (Table 1).

Table 1. Alternative hypotheses on spawning and movement conditions that support the observed seasonal fishery recruitment patterns.

Hypothesis (case)	Central Equatorial Pacific Spawning	Recruitment Mechanism	Spawning in the EPO or Hawaii
1	Seasonal	Uniform	Negligible
2	Seasonal	Seasonal	Negligible
3	Uniform	Seasonal	Negligible
4	Seasonal or Uniform	Negligible	Seasonal

The recruitment mechanism column of Table 1 refers to a physical process that provides an increased opportunity for skipjack to move between regions. Case 1 states that the cause of the recruitment pattern observed in the fishery data is due to spawning in the central Pacific. With a uniform intra-annual recruitment pattern, these skipjack are equally likely to move into the EPO or Hawaii at all times of the year but would pulse in because of the seasonal nature of central Pacific spawning. Cases 2 and 3 state that the majority of skipjack spawning takes place in the central Pacific, but that the opportunity to move between regions is not equal at all times of year. Under these hypotheses, seasonal oceanographic events create a "window" of recruitment opportunity for skipjack to move into the EPO and Hawaii from the central equatorial Pacific. Under Case 4, movement between regions is negligible and the majority of harvested skipjack represent products of local, seasonal spawning. An examination of the oceanographic dynamics can help evaluate each of these scenarios.

Temperature information was selected as the primary habitat indicator for skipjack spawning and/or recruitment mechanism. The abundance of skipjack larvae appears to be related to ambient water temperature (Matsumoto et al., 1984). The highest incidence of skipjack larvae occurs in surface waters from 23-28°. The presence of larvae indicates spawning in the vicinity (skipjack complete all larval stages in less than two weeks), thus examination of seasonal changes in sea surface temperature might suggest a seasonal recruitment mechanism. Alternatively, because skipjack larval stages are short and skipjack are found throughout the water column after metamorphosis, an investigation of mean temperature from the surface to 100 m was also pursued.

The sea surface monthly average temperature was based on the COADS (Woodruff et al., 1987) data set averaged over 1955-89. The monthly average temperature at depth was based on Levitus' (1982) data and was collated from 1946-81. The geographic resolution of the data were averaged over 2° latitude by 2° longitude grids. The software package

FERRET[1] specialises in manipulating gridded data sets and was used throughout this analysis.

The maps of average sea surface temperature by month showed distinct north-south shifts in addition to changes in the shape and size of the tropical warm-water mass (Figure 2). From February to May a warm water band (>24°C) between the EPO and central Pacific is broadest. From August to November this band becomes quite narrow. This corresponds to periods of relative weak and strong flows of the equatorial counter-current and seasonal variability in wind-driven equatorial upwelling. In Hawaii the sea surface temperature is usually warmer than 24° C and the warmest temperatures typically occurring in August - October. The general pattern is thus one of seasonal north-south shifts in warm surface waters, along with expansion and contraction of the warm water band between the EPO and central Pacific.

The mean water temperature from the surface to 100 m showed a different seasonal pattern than the sea surface temperature plots (Figure 3). Rather than a shift in the area of the warm-water band expanding into the EPO, there is a discontinuity of the central Pacific water mass extending into the EPO. This reflects the fact that the thermocline is much shallower in the eastern Pacific (Fiedler, 1992). Seasonally, there is an east-west shift in the temperature gradient due to local changes in thermocline depth. From February to June a pocket of "central Pacific water mass" develops and extends well into the EPO between 100-120°W longitude and 10-20°N latitude. This pocket subsequently recedes to the west and a band of relatively cold water persists east of 110°W from September to January. A similar pattern occurs south of the equator. In this region, however, the pocket of water is much smaller and less persistent. In Hawaii, the mean 0-100 m temperature plots show seasonal north-south shifts similar to the sea surface temperature figures.

To examine the magnitude of average seasonal differences between these two physical variables, areas representing the EPO, central equatorial Pacific (CEP), and Hawaii were selected for closer analysis (Figure 4). Within these areas, average temperatures by month indicated different patterns between regions (Figure 5). The sea surface temperature for the CEP region was always warmer (being closest to the equator), followed by the EPO and the Hawaiian region. In the Hawaiian region, as expected, the seasonal variability in sea surface temperature was greater than in the EPO region (CV=4% vs. 2% in the EPO). An opposite pattern was apparent for the average 0-100 m temperature data: the EPO region was always *colder* than the Hawaiian region, on average. Also the seasonal variability in the Hawaiian region temperature-at-depth data was *lower* than in the EPO (CV=3% vs. 5% in the EPO). The seasonal variability was lowest in the CEP for both measures of temperature (CVs<1%). The mean temperature over 0-100m depth in the EPO region exhibited more seasonal variability than did the average surface temperature in the Hawaiian region (even though the EPO region was closer to the equator).

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[1] Provided by the Pacific Marine Environment Laboratory, NOAA, 7600 Sand Point Way, Seattle WA 98115.

If temperature is a valid proxy for skipjack spawning and larval habitat and assuming the single-stock hypothesis is true, then the oceanographic data suggested mechanisms for the observed seasonal pattern of skipjack recruitment to the EPO and Hawaii. The opportunity for juveniles and skipjack in spawning condition to move to the EPO would be highest during periods when the warm-water band was broadest. If habitat is adequately indexed using temperature data, then having a larger "preferred" habitat during certain times of year may increase the chance for skipjack to move between regions. The mean temperature-at-depth data revealed more dynamic seasonal east-west processes than did the average sea surface temperature data. The mean temperature-at-depth figures characterised the habitat size along 3 dimensions, hence, it may have more accurately reflected habitat volume. As with the sea surface temperature data, an argument could be made that seasonal shifts in the physical environment may influence the incursion of skipjack from the central Pacific to the EPO and Hawaii.

With respect to recruitment timing estimated by Ianelli (1993), true age of the first age group was not assumed, consequently back calculation to month of spawning requires an added assumption. Assuming that the first age group represented 12-month old fish, then the peak spawning period of skipjack occurs about 3-4 months prior to the warmest times for both the EPO and Hawaii. Perhaps the most significant result from this is that the difference in the seasonal peak of skipjack recruitment in the EPO and Hawaii is roughly the same as the difference between peak periods of warm water for these regions. The peak temperatures are 6 months out of phase between regions as are the peak estimated recruitment periods. This suggests a link between the physical environment and the observed recruitment pattern to the fishery.

3. INTERANNUAL RECRUITMENT PATTERNS VS. SEA SURFACE TEMPERATURE ANOMALIES

The analysis presented in the previous section involved comparisons of monthly averages combined over several years with seasonal recruitment patterns observed from fishery data. Here, results from Ianelli (1993) are used to examine interannual variability of skipjack recruitment to the EPO. The estimated proportion at age of skipjack harvested in the northern portion of the EPO by month was compared with a time series of sea surface temperature anomalies. The purpose of this exercise was to determine if the added information of sea surface temperature anomalies helped explain the observed variability in fishery recruitment data.

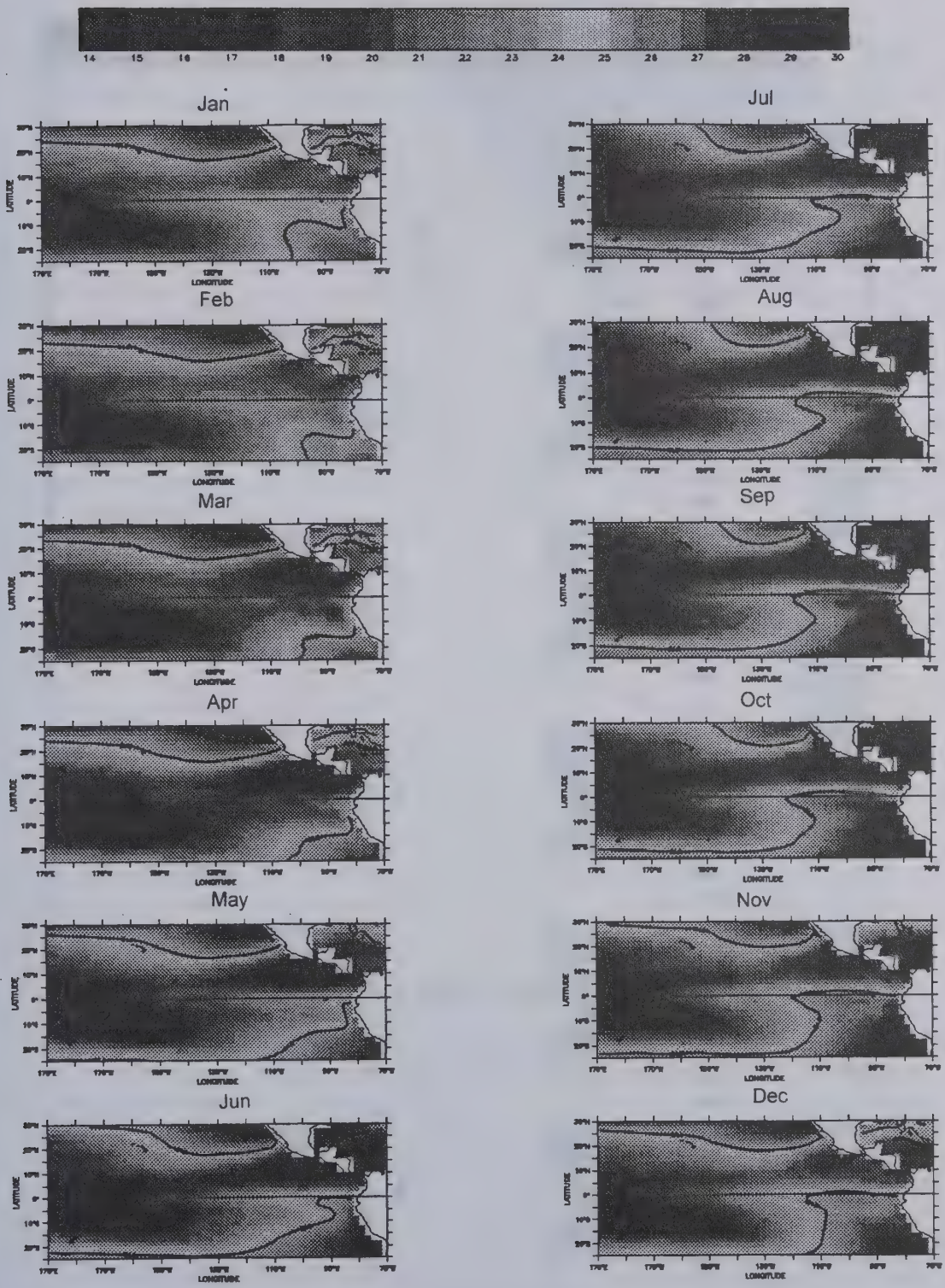

Figure 2. Mean monthly sea surface temperature based on COADS data (Woodruff et al., 1987) data. The solid line represents the 24° isotherm.

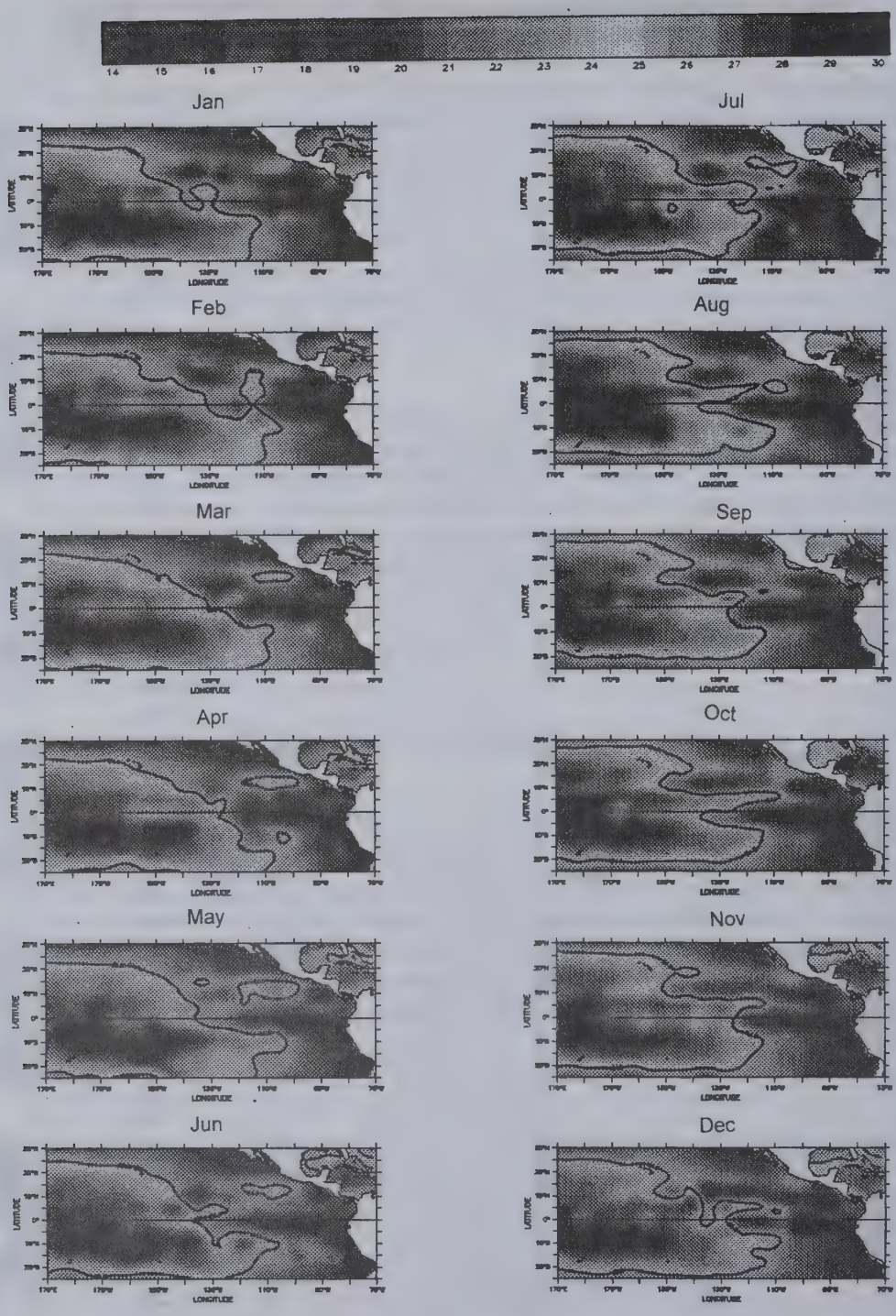

Figure 3. Mean monthly temperature from 0-100 m depth based on Levitus' (1982) data. The solid line represents the 24° isotherm.

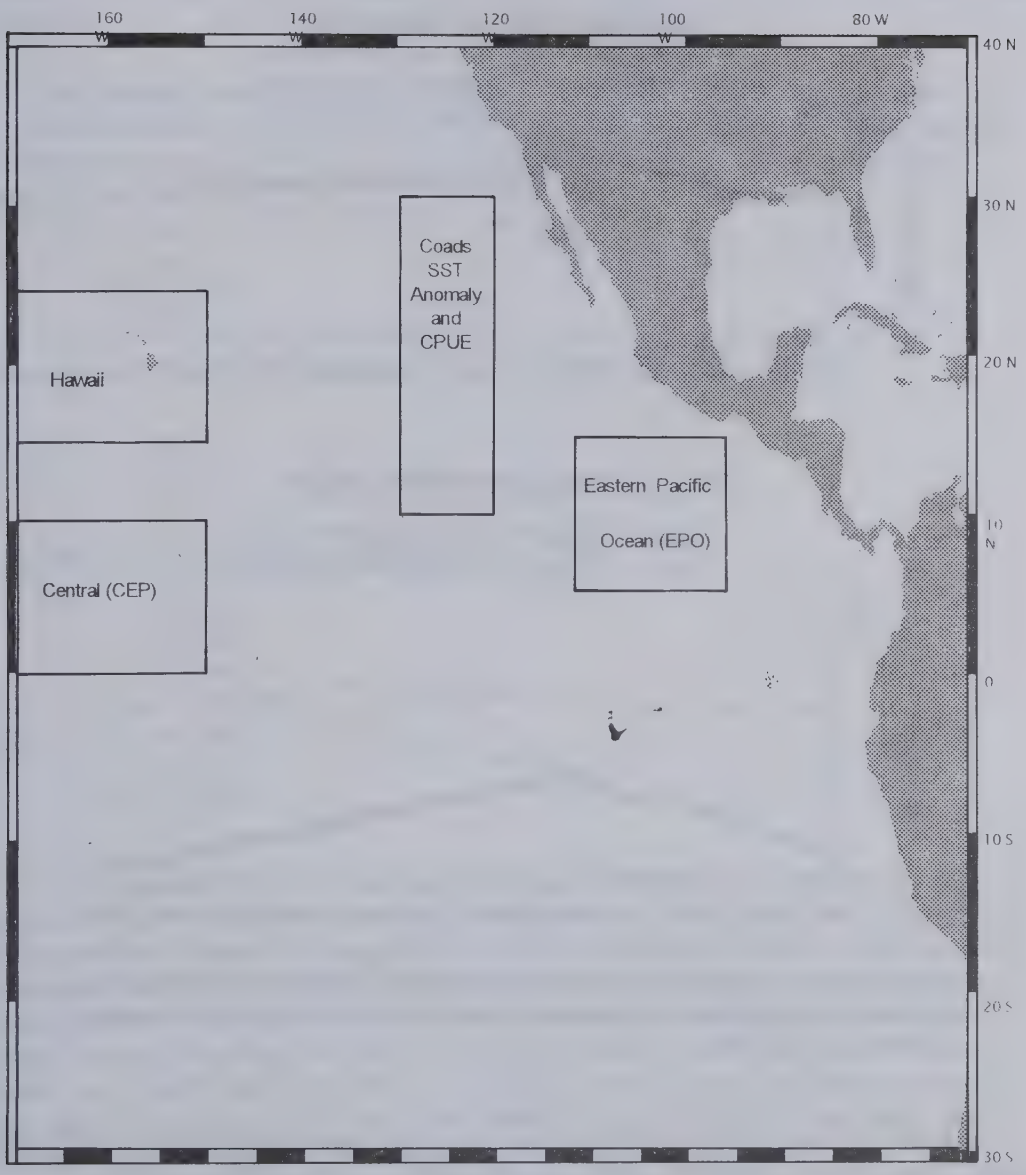

Figure 4. Locations selected for closer examination of seasonal and inter-annual patterns of physical variables and fishery catch data.

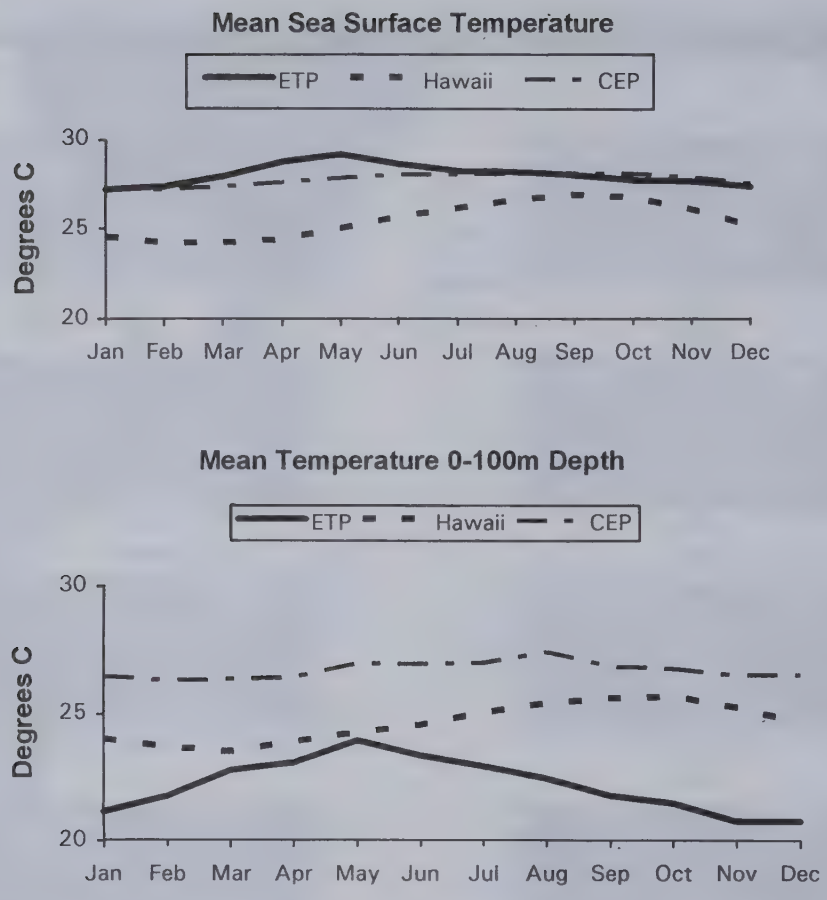

Figure 5. Seasonal temperature profiles using surface temperatures (upper panel) and average temperature to 100m depth by area. Refer to Figure 4. for the areas presented. ETP=EPO.

A monthly time series of sea surface temperature data was compiled from the COADS database from 1955 to 1990. First, the mean monthly sea surface temperature by 2° geographic grid was calculated over all years of observations. Then the anomalies were computed by subtracting the mean monthly values from each month-year observation. To capture the impact sea surface temperature anomalies may have on recruitment patterns to the EPO, the data were condensed as average anomalies for a geographic grid between 10-30°N and 120-130°W. This region was selected because it is longitudinally adjacent (primarily to the west of) the area where the fishery occurs. Also, this region is an area where the recruitment to the EPO is likely to take place based on the temperature pattern. The resulting time series (Figure 6) indicated a significant positive autocorrelation at about 50 months or slightly more than 4 years (Figure 7). This roughly coincides with the average period between El Niño events of 3.8 years as determined by Quinn et al. (1987) over the period 1803-1987. Also evident in this time series is a shift to warmer conditions in the mid-1970s. A similar shift has been observed by various authors (e.g., Hare and

Francis, 1995; Royer, 1993; Hollowed and Wooster, 1992) in different regions and in the Pacific.

Catch and catch rate index by year class were computed using monthly estimates of proportion at age (p_{ijk}) from Ianelli (1993). Catch (c_{ik}) and standardised effort (e_{ik}) data were supplied by the IATTC in 5° latitude x 5° longitude strata. The quantities were computed as:

$$C_{ij} = \sum_{k=1}^{12} p_{ijk} c_{ik}$$

where C_{ij} is the catch of age j individuals in year i, and for year class t,

$$C_{t\cdot} = \sum_{j=1}^{nages} C_{t+j,j}$$

Similarly, a CPUE index was calculated as:

$$U_{ij} = \sum_{k=1}^{12} \frac{p_{ijk} c_{ik}}{e_{ik}}$$

and

$$U_{t\cdot} = \sum_{j=1}^{nages} U_{t+j,j}$$

The time series of harvests and year-class index (CPUE) is presented in Figure 8. The harvest by year-class and CPUE index are closely related. Comparing these indices with the temperature anomalies is suggestive of a positive relationship, however the correlation is not significant (Figures 9 and 10). Part of the reason for the poor relationship may be that during the 1980s, there were fishery-driven factors not accounted for in the CPUE index. During this period, the fleet was changing rapidly and many high-performance vessels were leaving the EPO to fish in the western Pacific. Also, the change may have been due to the multispecies nature of the fishery. During this period, the catch rates for yellowfin tuna, the target species for this region, reached record highs levels.

4. DISCUSSION

Analyses of the seasonal aspects of the physical environment provided insights into the potential spawning patterns and recruitment mechanisms of skipjack. In the CEP the environmental conditions are seasonally stable, hence the spawning is not likely to be limited by water temperature. Skipjack larvae and juveniles from this region have been sampled in abundance during all quarters of the year (Nishikawa et al., 1985). Spawning in this region is therefore not likely to be influenced by seasons and Case 1 (Table 1) is also unlikely.

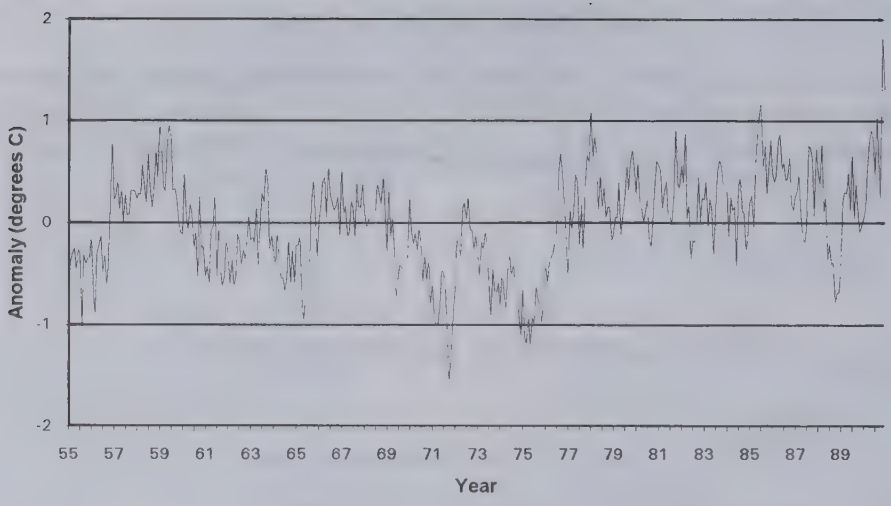

Figure 6. Monthly time series of data on the average sea surface temperature (SST) anomalies between 10-30°N and 120-130°W. (Data source: COADS, Woodruff et al., 1987).

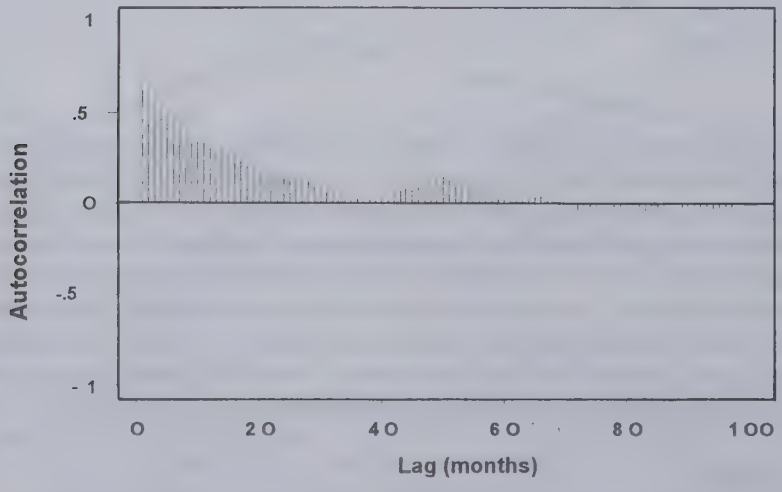

Figure 7. Autocorrelation function for the sea surface temperature anomaly time series.

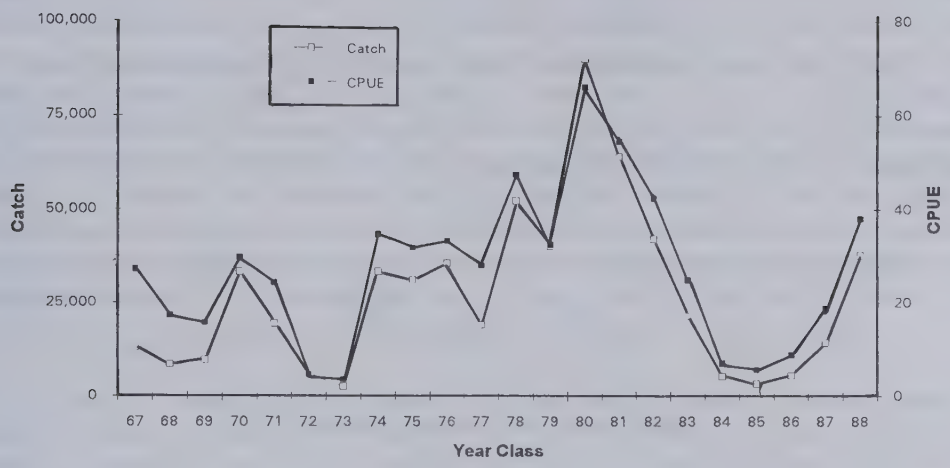

Figure 8. Plots of the annual time series of data on the month-adjusted year-class harvest of skipjack in the northern EPO.

Figure 9. Estimated index of annual skipjack cohorts and mean annual sea surface temperature anomalies plotted over time for the EPO north of 10°N. The open squares correspond to points in which catch may have been influenced by changes in the fishery.

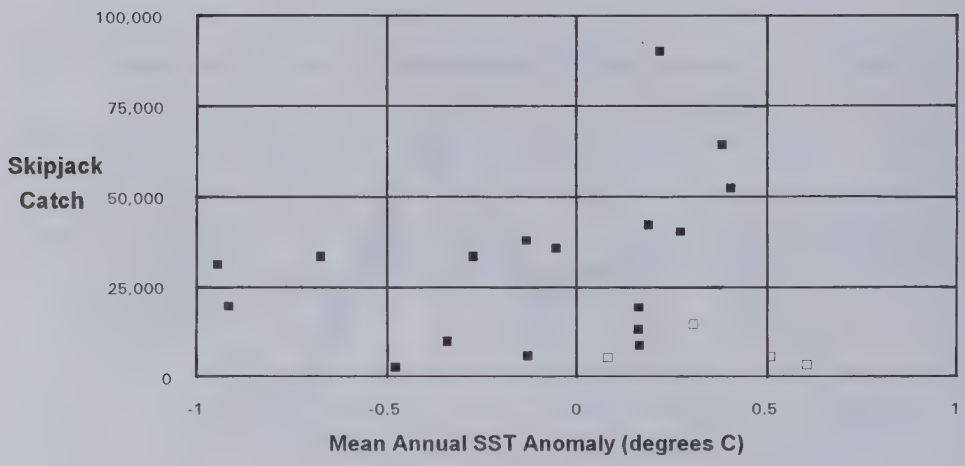

Figure 10. Estimated cumulative catch of skipjack cohorts versus mean annual sea surface temperature anomalies in the EPO north of 10°N. The open squares correspond to points in which catch may have been influenced by changes in the fishery.

The sea surface temperature and mean 0-100 m temperature data provided evidence of possible seasonal recruitment mechanisms between the CEP and the fishery regions. Of the hypotheses presented in Table 1, the argument for Case 3 is the strongest, considering the available information. If skipjack in the EPO and Hawaii came from seasonal spawning events in the CEP, then one would expect to see a similar recruitment pattern in these regions. The observed recruitment pattern between the EPO and Hawaii and the seasonal temperature peaks in these regions were both estimated to be six months out of phase. The underlying spawning pattern may not be strictly uniform, on average, over all months of the year. There may be two peak spawning periods operating on geographically distinct segments of the same stock. This gives conditional support for Case 2.

Recently, a concentration of skipjack larvae was found in the northern EPO (IATTC, pers. comm.). Based on the variables examined, there appears to be favourable spawning conditions in the EPO during the period February-May. This gives support to Case 4 (Table 1). The size of this region is restricted, however, and the extent to which spawning in the EPO contributes to the adult population may thus be relatively small. Based on the otolith analyses presented in Ianelli (1993), the skipjack from the EPO were similar to those from Hawaii during the early-life stages. If these samples represented typical harvests, then it is unlikely that skipjack spawning in local regions contributes substantially to subsequent recruitment. This conclusion is further corroborated by the general increase in abundance of skipjack larvae found toward the western Pacific (Matsumoto et al., 1984) and by a variety of earlier studies (e.g., Klawe, 1963; Rothschild, 1965; Joseph and Calkins, 1969; Williams, 1972).

Understanding processes that affect interannual recruitment variability is one of the more active areas of fisheries research. The role of the environment in recruitment variability has been the subject of debate since the early days of fishery science (Smith,

1988). The physical habitat of skipjack shows significant *intra*-annual spatial variability, however, the variability between years is greater. For example, the coefficient of variation for sea surface temperature between years was 5% versus the 2% observed for seasonal or intra-annual variability measure. The same can be said about recruitment of skipjack into the EPO and Hawaii. Based on the catch rate data presented, there are large interannual variations in skipjack abundance. Several oceanographic processes may contribute to the interannual variability not accounted for in this analysis. Forsbergh (1989) examined many physical variables and found an index of wind speed from the presumed spawning area to have the strongest relationship. In the present study, fewer physical variables were compared, however, the observations covered a broad area and allowed for a clear descriptive view on some aspects of the physical dynamics of skipjack habitat.

The degree to which the environment affects movement of skipjack between major oceanic regions is central to understanding their population structure. Quinn and Brodeur (1991) reviewed the variability of movement patterns for several different species of marine animals. They concluded that for many species environmental conditions influenced movement, but that responses to oceanographic conditions alone could not explain a large part of movement pattern variability. Based on analyses presented in this study, there appears to be a close link between skipjack spatial distribution and the dynamics of their habitat.

This study has focused on ways of analysing the stock structure of skipjack harvested in Hawaii and the eastern tropical Pacific. These areas were selected because of potential interaction between the fisheries in these regions and because of the effect of skipjack stock structure uncertainties on assessments. In addition to extensive oceanographic data, a relatively long time series of fishery data was available from both areas. This provided a unique opportunity to examine alternative hypotheses on skipjack stock structure in an area where the environmental dynamics are likely to play an important role in their distribution.

Different species of tuna have many life history characteristics in common. Tunas generally spawn in warm tropical water and have similar developmental stage durations (Bayliff, 1980). They are pelagic, broadcast spawners with positively buoyant eggs. Fecundity in tunas is high, with little variability in egg size between or within different species. Virtually all species of tunas have the ability to thermoregulate, although the vascular system can be different between genera. Similarities in other life history aspects become more variable between species. For example, Kearney (1991) remarked that:

> " . . . from a population dynamics perspective, southern bluefin tuna are more like lobsters than they are like skipjack."

From an ecological perspective, a natural ranking of tuna species can be made along the classic *r-selected* to *K-selected* spectrum (Table 2). An r-selected species is generally one that exhibits a high rate of intrinsic growth, reaches sexual maturity at a young age, has a small body size, and displays a relatively rapid population turnover. A K-selected species, on the other hand, typically grows slowly, reproduces at older ages, lives longer and can be characterised by having a relatively large number of age groups present in the population (Ricklefs, 1979). For both species of bluefin, the geographic area of spawning is restricted and spawning occurs over a relatively short period. Pacific albacore are divided into a

northern and southern stock and have larger but well defined spawning areas. The yellowfin tuna spawning area is larger and overlaps considerably with the skipjack spawning area. Skipjack have the largest spawning area of the species listed which is consistent with their rank in absolute abundance (highest). The comparisons of different species of tunas provide insight on stock-structure characteristics. Weighing the evidence of stock-structure types, K-selected species are more likely to have well-defined stocks. For skipjack, being at the r-selected end of the spectrum is consistent with the lack of evidence for discrete populations. Arguably, the lack of evidence for discrete stocks of skipjack may be due to the complexities that are beyond our current powers of observation.

Table 2. Biological characteristics of selected species of Pacific tuna (from Bayliff 1980).

Tuna Species	Age at Maturity	Approx. Longevity	Maximum Length	Estimated Natural Mortality	Size of Spawning Area	Evidence of Discrete Stocks
Skipjack (*Katsuwonus pelamis*)	1 yr	3-6 yr	90 cm	0.3-3.8	Largest	Low
Yellowfin (*Thunnus albacares*)	2-3 yr	10 yr	200 cm	0.6-1.6	Large	Moderate
Bigeye (*T. obesus*)	3 yr	10 yr	215 cm	0.4	Moderate ?	Moderate?
Albacore (*T. alalunga*)	4-5 yr	10 yr	145 cm	0.2	Moderate	Mod-high
Northern Bluefin (*T. thynnus*)	3-4 yr	10 yr	250 cm	0.2-0.3	Small	High
Southern Bluefin (*T. maccoyii*)	5-6 yr	20 yr	220 cm	0.2-0.3	Small	High

5. SUMMARY

Studies using genetics, tagging, growth, distributional analyses, parasites, and catch rates have been conducted to elucidate skipjack stock structure in various regions of the Pacific (Table 3). Each method has weaknesses. Synthesising all information, the ability to reject or accept particular stock structure hypotheses is not great.

The physical habitat of skipjack (water temperature) was qualitatively compared with results from analyses of the fishery data. Sea surface temperatures were examined for intra-annual and interannual variability and compared with fishery data on the same scale. Additionally, mean 0-100 m temperature was used to examine the three-dimensional dynamics of skipjack habitat. Results from this study indicated that the mean temperature-at-depth data reveals more dynamic seasonal east-west processes than the average sea surface temperature data. These processes are more likely to play an important role in the recruitment of skipjack into the EPO. The interannual variability was greater than the intra-annual (seasonal) variability in sea surface temperature anomalies. The relationship between the mean anomalies and fishery year-class index suggested a weak but insignificant positive correlation.

Table 3. Summary of results of methods to investigate skipjack population structure and the implications for management (modified from Argue et al. (1986) and added to from Ianelli (1993)).

Method	Results Pertaining to Population Structure	Management Utility
Blood genetics	SPC analyses support a clinal hypothesis, but it is unclear how the cline is maintained. Other investigators using different blood genetics data have inferred genetically isolated subpopulations.	Subjective and conflicting evidence of potential for fishery interactions.
Tagging	No oceanic barriers to migration. Conditional support for clinal hypothesis.	Quantification of population parameters and fishery interactions.
Growth	Estimates of growth parameters vary in space and time suggesting a strong environmental rather than genetic effect.	Estimation of yield.
Juvenile distribution/ maturity	Juvenile and spawning skipjack appear concentrated at longitudinal extremes of the study area. Conditional support for isolated subpopulation hypotheses.	Delineation of areas where spawning may be concentrated.
Parasites	No evidence of discrete subpopulations.	Evidence of movement between tropical and subtropical waters.
Catch Rate Analyses	Suggests several discrete units related to apparent abundance concentrations.	Patchy distribution may relate to environmental conditions useful in forecasting
Microconstituent analyses	Similarities between eastern Pacific and Hawaiian skipjack during early life stage but differences detected with ontogeny.	Evidence of potential for fishery interaction.
Length frequency analyses	Similar recruitment patterns between skipjack in the north and south EPO. These patterns differ from Hawaiian skipjack	Recruitment of skipjack to the EPO and Hawaii differs in its seasonal periods suggesting that brood conditions tend to be independent.
Physical habitat	Descriptive overview of habitat dynamics indicating seasonal shift to both EPO and Hawaiian archipelago.	Evidence of potential for fishery interaction, useful for forecasting
Comparisons with other species	Suggestion that skipjack has a low potential for maintaining discrete stocks	Evidence of potential for fishery interaction.

From these and other analyses, two competing hypotheses of the skipjack stock structure in the eastern and central Pacific can be proposed. First, the majority of skipjack production for the respective fisheries is based on a single stock that spawns over an extended period in the central Pacific. The pattern of different cohort seasonality between the areas may be due to an extended spawning season where eastward migration of the larval and juvenile stages is based on seasonal extensions of the equatorial water masses. Second, relatively distinct stocks with different peak spawning periods in the same region may explain the observed seasonality of brood events. Arguments in favour of the latter hypothesis, however, require a high degree of spatial and temporal assortative behaviour between the stocks. This is not well supported by studies on the mixing rates between schools. Bayliff (1988) and Hilborn (1991) estimated that the individual turnover rate within schools is high. Thus, if schools from different stocks occur in the same region and mixed at the rates estimated, then they would have to somehow have to regroup themselves into respective stocks for reproduction. While such a feat would be remarkable, it seems unlikely to provide substantial gains in terms of overall reproductive fitness.

The question remains, what role does migration play in the stock structure of skipjack in the central and eastern Pacific? Fish migration can be treated like any other evolutionary adaptation: its function is to increase reproductive fitness. For skipjack to have populations that exhibit a migratory propensity, the benefits of doing so must be significant. There must be an energetic "reward" (increase in fitness) over the long term. Other tuna species that have well-defined population structures make non-spawning migrations. For example,

in Japan the IATTC tagged several 3-4 month-old northern bluefin (*Thunnus thynnus*). Roughly one year later fish tagged within days of each other were recaptured on both sides of the Pacific. For some reason part of the young-of-the-year cohort travelled to the eastern Pacific while others remained in the waters off Japan. This suggests that non-spawning migration tendencies may not be inherited, or if they are, the quantitative genetic traits involved are highly variable. A similar argument could be made for EPO skipjack. I believe that skipjack that migrate to the EPO are not necessarily the progeny of adult skipjack that have also migrated to the EPO. There may be phenotypic traits that influence individual propensity for long migrations, but such individuals are not likely to constitute a stock. It is possible that a stock may have evolved to spawn during specific seasons to take advantage of environmental conditions conducive to eastward movement as juveniles and larvae.

Migration, homing, or the general tendency to disperse (i.e., diffusive behaviour) can affect the potential for interaction between fisheries. Different levels of homing and dispersion have implications for regional management effectiveness and for the potential for interaction between fisheries (Table 4). If the level of dispersal is low and the migration/homing propensity is low, then there is a moderate chance for effective regional management. Under all other scenarios, the potential for interaction between fisheries is high. The potential for interaction implies that exploitation rates in different areas are significant relative to the total population turnover rate. Ultimately, under the multiple or single stock hypothesis, the effectiveness of local management regimes will suffer without cooperative, transboundary harvest strategies and assessments.

Table 4. Summary of competing mechanisms for alternative hypothesis on the stock structure of skipjack in the Pacific and the likely impact on potential local management and fishery interaction (Modified from Kleiber et al., 1987).

Stock Structure Hypothesis	Level of Dispersal w/in Habitat	Migration/ Homing Propensity	Potential for Effective Local Management	Potential for Fishery Interaction
Single	Extensive	Low	Low	High
Single	Low	Low	Mod	Low
Single	Low	Extensive	Low	High
Multiple stocks	Extensive	Low	Low	High in mixing zone, low in breeding areas
Multiple stocks	Low	Extensive	Low	High in mixing zone and in breeding areas

6. ACKNOWLEDGEMENTS

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SKIPJACK MOVEMENT AND FISHERIES INTERACTION IN THE WESTERN PACIFIC

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ABSTRACT

An advection-diffusion model in which movement parameters are variable in both time and space is applied to the analysis of skipjack tag and recapture data. Two data sets spanning the periods 1977-1982 and 1989-1992 are analysed. The results indicate that skipjack movement is highly variable in time and space with very little coherent pattern. The estimated movement pattern mortality and catchability coefficients, and observed patterns of fishing effort for the period 1989-1992, are used in a general model of the skipjack fisheries in the western Pacific. The model predicts that the pole and line yield may have declined by as much as 20% due to the activities of the purse seine fishery. We conclude, however, that a change of this magnitude would be difficult to detect in actual recorded catches.

1. INTRODUCTION

A quantitative method to describe large scale movement of fish is necessary to predict the effects of a fishery operating in one place on the yield of a fishery operating in another place. Such descriptions comprise movement patterns. The purpose of this paper is to examine movement patterns of skipjack in the western Pacific ocean and to attempt to determine how these patterns may change over time.

A model of the large scale net movements of tagged skipjack is used to estimate movment patterns. In this model, movement is partitioned into directed and dispersive components. The directed component refers to net displacement in a unique direction. The dispersive component, also referred to as diffusion, is an essentially random process. Description of fish movement as "random" poses difficulties for behaviorists who claim with justification that the behavior of individual animals is not random. Movements of individual skipjack on a small scale may have well determined causes such as pursuit of prey, avoidance of predators, or preference for water with certain properties. Although individuals may never move at random on a small scale, there may be considerable variation in the population,

and descriptions of large scale movements of populations should incorporate this variability. The relative importance of directed and dispersive movement in determining the distribution of skipjack populations at different scales will also be analyzed. Finally the potential impact of expanding purse seine fisheries on pole and line fisheries for skipjack will be discussed.

2. METHODS: ESTIMATION OF MOVEMENT PATTERN

Movement patterns were estimated from tag and recapture data using a population dynamics model that explicitly incorporates movement. A preliminary version of the model was presented to the First FAO Expert Consultation on Interactions of Pacific Tuna Fisheries (Sibert and Fournier, 1994). Additional model structure, including spatially variable diffusion, monthly changes in fishing mortality, and fleet-specific tag reporting rates, has been added since that presentation. A mathematical summary of the model is presented in the Appendix.

The model partitions the change in population density of tagged skipjack at a point in the ocean between movement and mortality. Movement is modeled using the generalized advection-diffusion partial differential equation; see equation (2) in the Appendix. While this equation is usually considered to describe transport of a solute in a moving fluid, it is also the limiting case of a biased random walk and can be used to describe movements of animals (Okubo, 1980). This formulation recognizes two types of behavior: directed movement represented by the vector (u, v) (also called advection) and random movement represented by D (also called diffusion). Mortality is modeled as the sum of mortality due to fishing and natural mortality. Mortality due to fishing is proportional to the nominal fishing effort reported by each fleet operating in the model area and thus varies over time and space. Natural mortality is assumed to be constant throughout the model area and is properly interpreted as mortality not attributable to either fishing or to movement. The area to which the model is applied is closed so that there is no possibility that emigration from the model area can be confused with mortality. In the absence of mortality, the total number of tagged skipjack in the model area remains constant however large the variation may be in the number at any single point.

The southern boundary of the model area is 25° S latitude, the northern boundary is 10° N latitude, the western boundary is 130° E longitude, and the eastern boundary is 170° W longitude. This model area covers approximately 7.5×10^6 nm^2. Regions within the model area are defined as geographical subdivisions of the model area, and Seasons are defined periods of time over which the movement parameters (u, v, D) are constant. The model area and the ten regions within it used to analyze the data are shown in Figure 1. Skipjack movements are considered to be seasonal in parts of their range. Movements for two seasons were estimated, Season 1 (from April through September) and Season 2 (from October through March). Selection of seasons is largely arbitrary. Anecdotal evidence suggests that skipjack movements may be seasonal and the two seasons selected correspond to the southern hemisphere cold and warm seasons, respectively.

The borders of the model area and are arbitrary. Simulation results reported by Sibert and Fournier (1994) indicate that parameter estimates can be inaccurate for regions in which no tags were recovered. Therefore, the model area and regions shown in Figure 1 were established so that there were recaptures in all regions during each season.

The advection-diffusion equation treats a quantity as continuous in time and space. Numerical solutions of the equation on a computer require that it be discretized in time and space. Although, in principle, the resolution of the numerical model is limited only by the resolution of the data, in practice, spatial resolution is constrained by computer

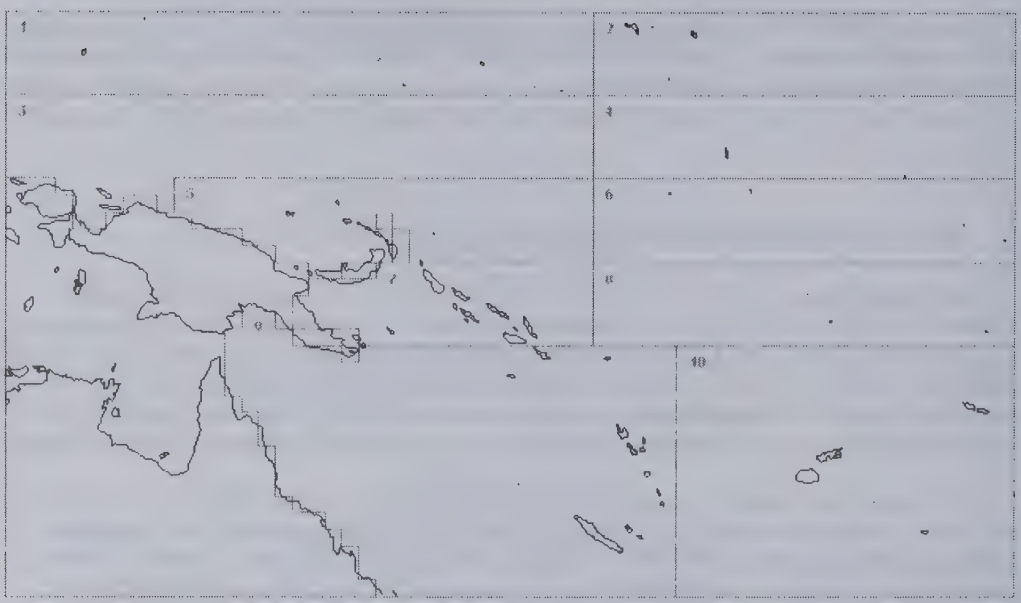


Figure 1. Map of southwest Pacific ocean showing the model area and the locations of regions within it. The model resolution of the coastlines of Australia and Papua New Guinea is also indicated.

memory limitations and temporal resolution is constrained by the time one is willing to wait for a sufficiently accurate solution. The spatial resolution used in the present analysis is 60 nm and the temporal resolution of the data is one month.

The model requires two types of data, tag release and recapture data, and fishing effort data. All data are aggregated to one degree square by one month strata. A tag cohort is defined as the sum of all tagged skipjack released in a one degree geographic square during a month. Aggregation of the tag release data to this level means that all tags released during one month are assumed to mix instantaneously throughout the one degree geographic square in which they were released.

Tag and recapture data from two different South Pacific Commission (SPC) studies were used, the Skipjack Survey and Assessment Programme (SSAP), 1977-1982, and the Regional Tuna Tagging Programme (RTTP), 1989-1992. The SSAP released 87,941 tagged skipjack in 102 cohorts in the model area, and the RTTP released 77,962 tagged skipjack in 237 cohorts in the same area. Recaptured tags are only useful in this analysis when reported with recapture position, date and fleet. There were 4,018 recaptured tags reported to the SSAP and 6,258 to the RTTP within the model area with useable recapture information.

Fishing effort data were obtained from a variety of sources including daily fishing logs reported to Pacific island states and forwarded to the SPC, published data summaries, and data supplied to the SPC by fishing nations. Fishing effort data for the model are nominal fishing effort expressed in boat-days fished per month in each $1° \times 1°$ geographic square. Gear types included are pole and line and purse seine, the two principal gear types that exploit skipjack in the western Pacific. Fishing nations include Fiji, Japan, Kiribati, Korea, Papua New Guinea, Philippines, Solomon Islands, Taiwan, and USA.

The proportion of tags recaptured in the fishery and returned to the SPC with useful information is defined as the reporting rate (see Appendix). In the absence of fleet specific

estimates, a reporting rate of 1.0 is assumed for all fleets returning tags to the SSAP. Reporting rates for the RTTP were estimated for each fleet on the basis of tag seeding results and other information (SPC, 1994). Reporting rates were multiplied by (i) the proportions of tags returned by each fleet that had accompanying data of sufficient resolution to be included in the analysis and by (ii) the global value, 0.923, the proportion of all tag returns in the model area accounted for by the fleets included in this analysis. The resulting overall fleet-specific reporting rates are given in Table 1.

Table 1. Reporting rates used for estimation of movement patterns.

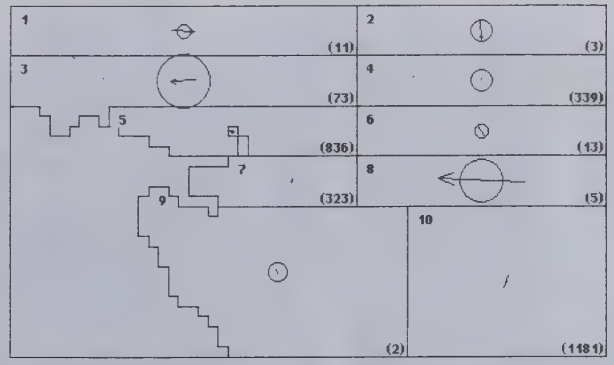
Fleet	SSAP	RTTP
Fiji pole and line	1.0	0.826
Japan pole and line	1.0	0.376
Japan purse seine	1.0	0.360
Kiribiti pole and line	—	0.646
Korea purse seine	—	0.026
Papua New Guinea pole and line	1.0	—
Philipines purse seine	—	0.669
Solomon Islands pole and line	1.0	0.660
Solomon Islands purse seine	—	0.713
Taiwan purse seine	—	0.016
United States purse seine	—	0.509

3. RESULTS: MOVEMENT PATTERN

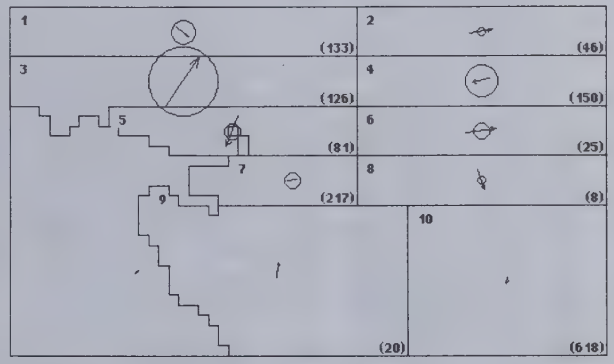
The movement pattern estimated from the SSAP data is shown in Figure 2A. The most prominent feature of this pattern is the variability between regions and seasons in both directed and dispersive components of movement. In spite of this variability there are some common features. There is a consistent eastward tendency in the directed component in the regions between 5° and 10° N, most prominent in Region 1. Rates of roth directed and dispersive movements estimated for Region 10 are rather low, particularly in Season 2.

The persistence of the movement pattern in the SSAP data was tested by dividing the tag releases into two time periods: (A) October 1977 through September 1978 (47 cohorts released) and (B) October 1978 through August 1980 (55 cohorts released). The mortality parameters (M, Q_i) were fixed at the values estimated for the overall SSAP data set and the movement parameters (u, v, D) were estimated separately for the two time periods. The value of the negative log likelihood function (equation 8 in Appendix A) for the overall data set is 11,696.03 and there are 60 estimated movement parameters. The combined negative log likelihood for the two time periods is 11,620.49 and there are 120 movement parameters (60 for each time period). The model with separate movement parameters thus fits the data better (lower negative log likelihood) than the overall model. The significance of this improvement in fit can be tested using a likelihood ratio test (Brownlee, 1965) in which twice the difference between the negative log likelihood for the two models is interpreted as a χ^2 variable with degrees of freedom equal to the difference in numbers of parameters in the two models. In this case the χ^2 value is 75.55, the degrees of freedom is 60, and the improvement in fit of the 120 parameter two period model is significant with $0.05 < \alpha < 0.10$. Therefore there are significant differences between the movement patterns for the two periods.

The role of dispersive movments was tested by fitting the SSAP data set to a model in which dispersive movements were constrained to be zero; that is, all movement was

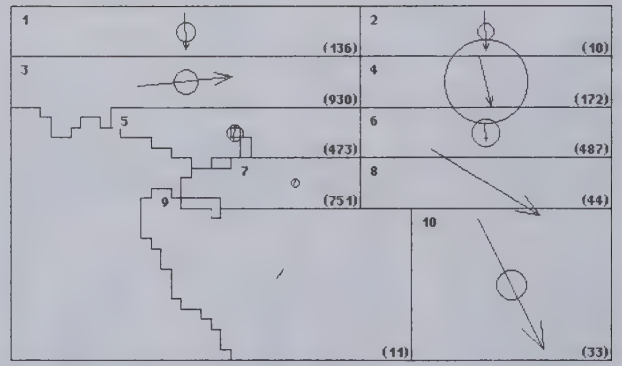


Season 1 (4..9)

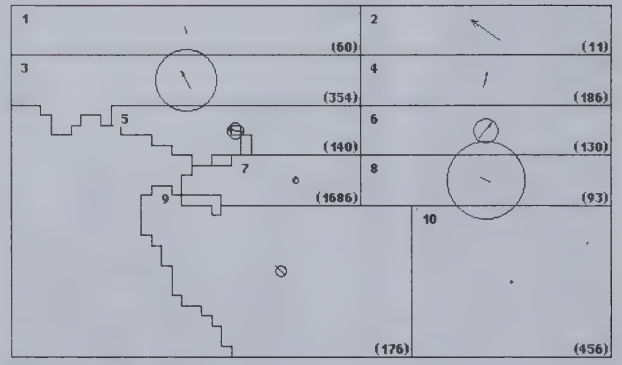


Season 2 (10..3)

A. SSAP



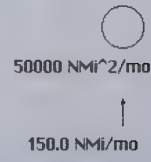
Season 1 (4..9)



Season 2 (10..3)

B. RTTP

Figure 2. Skipjack movement patterns estimated from SSAP (A.) and RTTP (B.) tag returns. The number in the upper left corner of each region is the region number. The number (in parentheses) in the lower right corner of each region is the region number of tags returned from that region during a season. The area of the circles is proportional to the rate of dispersive movement. The length of the arrows is proportional to the directed movement rate in the direction indicated. The radius of the circles and the length of the arrows are drawn to the same scale as indicated at the right.



assumed to be directed. This model produced a negative log likelihood value of 12,759.00 with 26 parameters compared to the complete model with a negative log likelihood values of 11,696.03 with 66 parameters. The improvement in fit of the complete model is significant with $\alpha < 0.001$. Similarly a model was fit in which the directed movements were constrained to be zero; that is, all movement is assumed to be dispersive. Again the complete model fits the data significantly better with $\alpha < 0.001$. These tests indicate that both dispersive and directed movements are required to describe the movements of tagged skipjack during the SSAP.

The overall movement pattern estimated for the RTTP is shown in Figure 2B. Although the details are quite different, the degree of regional and seasonal variability is similar to that estimated for the SSAP. The eastward directed movement appears to have shifted to the band between the equator and 5° N (Region 3, Season 1) and the lack of movement in Region 10 during Season 2 is still detectable. The year to year variability was tested by dividing the RTTP tag releases into two groups: (A) those released between July 1989 and October 1990 (86 cohorts) and (B) those released between February 1991 and December 1992 (151 cohorts). The difference in movement pattern between the two years is significant with $\alpha < 0.001$.

The relative importance of dispersive and directed movement components can be expressed by a dimensionless ichthyokinematic ratio, R, computed as

$$R = \frac{V\ell}{D}$$

where $V = \sqrt{u^2 + v^2}$ is the magnitude of the resultant vector formed by the u, v components of directed movement and ℓ is a characteristic movement length. Values of R greater than one indicate that directed movements are more important than dispersive movements over distances specified by the characteristic length. This ratio is similar to the Peclet number (Huyakorn and Pinder, 1983; Boudreau, 1986) and can be considered as a Reynolds number for the movement of fish. Values of R less than one indicate that dispersive movements are more important than directed movements over a distance specified by the characteristic length. Table 2 shows values of R computed for three values of ℓ characteristic of the model resolution (60 nm), a scale typical of an Exclusive Economic Zone (200 nm), and a longer distance (1,000 nm). At the model scale, dispersive movements are dominant; as the scale of movement (ℓ) is increased, directed movements become dominant.

Movement and mortality are integral components of population dynamics. The estimated catchability and natural mortality coefficients along with estimates of their standard deviations are given in Table 3. Natural mortality was estimated to be approximately $0.07^{-\text{mo}}$ for the SSAP and near zero for the RTTP. Catchability coefficients vary more between gear types than between the SSAP and the RTTP data sets. Catchabilities for purse seine fleets range from 0.001 to 0.05 while catchabilities for pole and line fleets are approximately an order of magnitude lower.

4. RESULTS: FISHERY INTERACTION

The impact of expanding purse seine fisheries on pole and line fisheries is one of the major preoccupations in the analysis of fishery interaction. Analysis of the RTTP data provides estimates of fishing mortality by four pole and line, six purse seine fleets and other parameters necessary to model regionally expanding fisheries. The population model described in the Appendix was used to simulate the skipjack population and fisheries that

Table 2. Ichthyokinematic ratios for SSAP and RTTP analyses. Movement parameters u, v (in nautical miles per day) and D (in square nautical miles per month) are shown for each region and season. Dimensionless dispersion indices are calculated for three different scales of movement: 60, 200 and 1,000 nautical miles.

		Parameters			Ichthyokinematic Ratio		
Season	Region	u	v	D	60	200	1000
		SSAP Analysis					
1	1	4.67	-0.15	7097	1.19	3.95	19.76
	2	0.25	-4.16	14811	0.51	1.69	8.43
	3	-5.00	-0.36	84576	0.11	0.36	1.78
	4	-0.46	-0.41	15666	0.07	0.24	1.19
	5	-1.00	0.28	250	7.45	24.82	124.11
	6	-1.09	2.13	5431	0.79	2.65	13.23
	7	-0.26	-0.91	0	$\gg 1$	$\gg 1$	$\gg 1$
	8	-17.77	1.00	56448	0.57	1.89	9.46
	9	-0.03	0.79	11658	0.12	0.41	2.03
	10	0.95	2.39	35	131.55	438.49	2192.45
2	1	2.27	-2.07	19207	0.29	0.96	4.79
	2	4.68	0.98	3006	2.86	9.54	47.69
	3	6.82	10.05	148720	0.15	0.49	2.45
	4	-3.65	-0.72	32531	0.21	0.69	3.43
	5	-2.50	-6.47	8895	1.40	4.68	23.38
	6	6.47	1.05	8773	1.34	4.48	22.41
	7	1.82	0.03	8786	0.37	1.24	6.20
	8	1.23	-4.12	2470	3.14	10.45	52.25
	9	0.29	2.85	0	$\gg 1$	$\gg 1$	$\gg 1$
	10	-0.49	-1.25	321	7.51	25.04	125.19
		RTTP Analysis					
1	1	0.03	-7.56	12269	1.11	3.70	18.50
	2	0.03	-7.85	9404	1.50	5.01	25.03
	3	19.02	2.11	16976	2.03	6.76	33.82
	4	2.50	-10.24	206440	0.09	0.31	1.53
	5	0.45	3.13	9564	0.59	1.98	9.91
	6	0.04	-3.63	22508	0.29	0.97	4.84
	7	-0.19	-0.69	1861	0.69	2.30	11.48
	8	22.09	-13.48	10	4735.31	15784.38	78921.90
	9	-1.39	-1.69	0	$\gg 1$	$\gg 1$	$\gg 1$
	10	13.51	-26.22	27588	1.92	6.42	32.08
2	1	-0.33	1.49	1	2275.39	7584.64	37923.22
	2	-5.71	4.07	0	$\gg 1$	$\gg 1$	$\gg 1$
	3	-1.95	3.43	117402	0.06	0.20	1.01
	4	0.65	3.00	98	56.13	187.09	935.47
	5	-3.11	1.04	9591	0.62	2.05	10.26
	6	2.46	3.04	18853	0.37	1.24	6.22
	7	-0.07	-1.23	1163	1.90	6.34	31.68
	8	1.75	-0.71	174947	0.02	0.06	0.32
	9	-1.93	1.78	4536	1.04	3.47	17.34
	10	-0.37	-0.01	409	1.62	5.41	27.06

Table 3. Estimates of global natural mortality (M) and catchability (Q_f) by fleet for the SSAP and RTTP analyses. Numbers set in small type to the left and right of the estimates are the estimated lower and upper 95% confidence limits of the parameter estimates. A dash indicates that the fleet was inactive.

	SSAP			RTTP		
M	0.067962	0.074339	0.080950	0	0.000000	0.001713
Q_f						
Fiji P&L	0.004630	0.004947	0.005274	0.003932	0.004575	0.005264
Japan P&L	0.001720	0.001991	0.002280	0.000507	0.000624	0.000753
Kiribati P&L		—		0.001062	0.001385	0.001749
Papua New Guinea P&L	0.000522	0.000569	0.000617		—	
Solomon Islands P&L	0.000525	0.000594	0.000668	0.000537	0.000588	0.000642
Japan PS	0.005294	0.006737	0.008340	0.015577	0.016898	0.018260
Korea PS		—		0.040285	0.049578	0.058885
Philipines PS		—		0.008769	0.009477	0.010209
Solomon Islands PS		—		0.012241	0.013382	0.014566
Taiwan PS		—		0.009570	0.012664	0.016121
United States PS		—		0.001062	0.001385	0.001749

exploit it. The average monthly distribution of fishing effort for each of the 10 fleets used in the RTTP analysis was calculated by averaging over years from 1989 through 1993. These averages were used to simulate the current distribution of fishing by these fleets.

The population was initialized at zero and allowed to grow by the process of constant monthly recruitment without fishing for 120 months until a steady state was approached (see equation (10) of the Appendix). At that point, simulated pole and line fisheries began to operate at current levels of effort. Simulated purse seine effort was increased in ten steps from zero to two times the current effort levels. Effort was held constant for 24 months after each increase to allow the system to approach equilibrium. The histories of purse seine yield and pole and line yield summed over all fleets starting in month 120 is shown in Figure 3. The stepwise growth of the purse seine yield and decline in pole and line yield can be seen. The pole and line yield relative to the pole and line yield at zero purse seine effort was computed for each fleet and for the sum of all pole and line fleets. The results are shown graphically in Figure 4. It would appear that the current pole and line yield is approximately 80% of what might have been attained at zero purse seine effort. The decline is greatest for those pole and line fleets operating nearest the large scale purse seine fleets (Japan, Kiribati) and least for those pole and line fleets operating farther away (Fiji).

Estimates of natural mortality are known to influence estimates of interaction potential (Sibert, 1984). The interaction analysis was repeated at three different levels of natural mortality by setting the numerical value of M to a constant and estimating the movement and catchability parameters. The resulting parameter estimates were used to estimate theoretical reductions in pole and line yields at current purse seine effort levels. The results are presented in Table 4. The potential for interaction generally decreases as natural mortality increases, although the trend in not monotonic, as in the case of Solomon Islands.

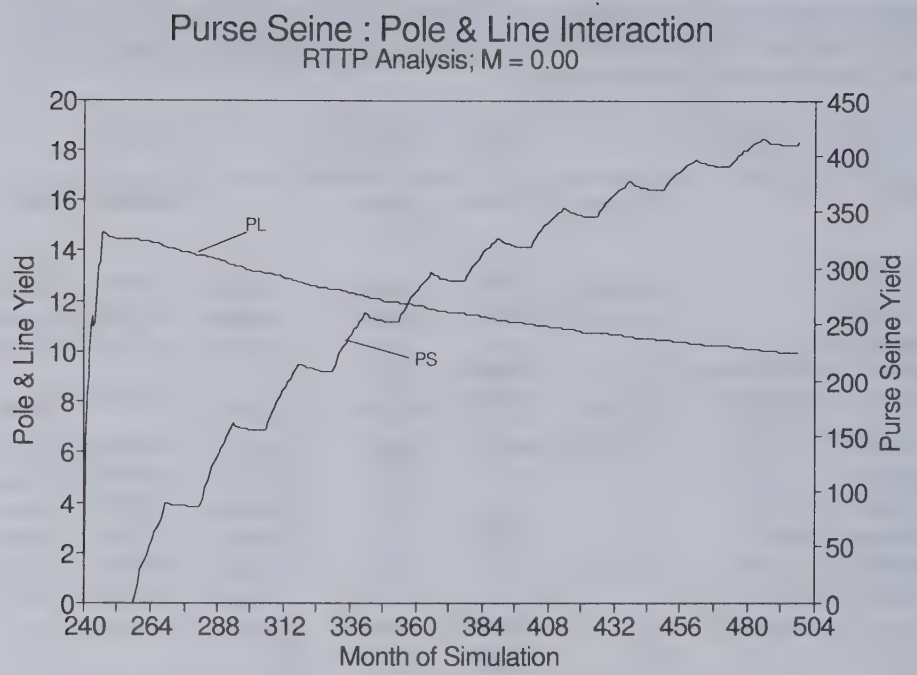


Figure 3. Simulated growth of the purse seine (PS) fishery from zero to two times its current effort levels and the hypothetical effect on the pole and line (PL) fishery. The duration of the simulation is 22 years.

5. DISCUSSION AND CONCLUSION

One of the striking features of these results is the large variability in both directed and dispersive components of movement between seasons and between regions (Table 2, Figure 2). The variability in the dispersive components (D) seems particularly large in relation to the directed components (u, v), but it must be remembered that the units of D contain the square term, nm^2, whereas the units of u, v are linear. The relative radii of the circles in Figure 2 are a better indicator of the relative magnitude of the variability in D than simple comparisons of the numerical point estimates. The parameterization of the advection-diffusion PDE used in this analysis associates the movement parameters with specific region-season strata. It is therefore difficult and probably not meaningful to attempt to interpret the parameter estimates as functions of environmental variables such as water temperature, circulation or topography.

Consistent large scale directed movement is one of the characteristics of animal migration. Skipjack are classified as "highly migratory" species, yet there appears to be little coherent pattern or temporal consistency in skipjack movement at any scale. Nevertheless, the hypothesis of totally random movement (i.e., $(u, v) = 0$) has been rejected. The extent to which skipjack movements can be regarded as random depends on the scale of the movement. Although it is doubtful that individual fish ever move randomly, random movement generally appears to be the dominant mode over shorter distances. Directed movements are generally dominant at larger scales, although in some region-Season strata, dispersive movements are dominant. One of the few consistencies is the eastward movement north of the equator during the SSAP period. One obvious explanation for this movement is transport in the North Equatorial Counter Current. It would be relatively simple to incorporate such water movements into the model and to test the significance of physical transport of fish by

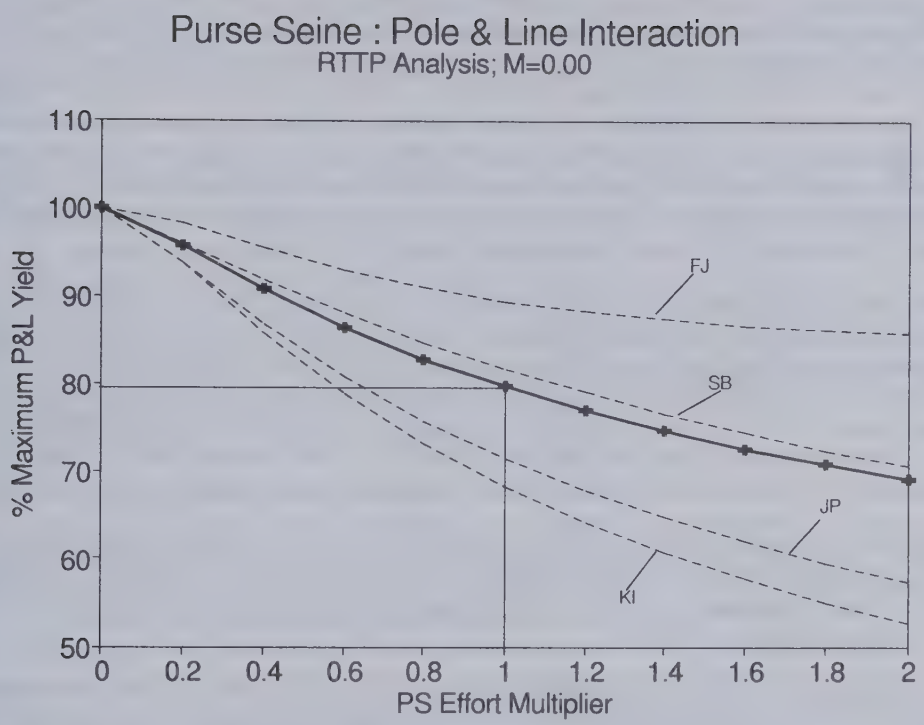


Figure 4. Hypothetical decline in relative pole and line (PL) yield in response to relative increases in purse seine (PS) effort. Lines labeled FJ, SB, JP, and KI indicate yield from the pole and line fisheries of Fiji, Solomon Islands, Japan, and Kiribati, respectively. Crosses indicate the average PL yield.

Table 4. Potential percentage reduction in yield of pole and line fisheries at different levels of natural mortality (M) at current purse seine effort levels relative to pole and line yield without purse seine fisheries.

	Potential Reduction by Fleet			
M	Fiji	Solomon Islands	Japan	Kiribati
0.0	10.6 %	18.4 %	28.5 %	31.7 %
0.07	5.3 %	16.4 %	23.3 %	25.5 %
0.15	2.4 %	28.4 %	21.4 %	20.5 %

ocean currents in determining the distribution of skipjack.

The models used in this analysis are spatially disaggregated population dynamics models with a resolution of 1° square. They attempt to describe population dynamics on a local scale in contrast to the more conventional approach of attempting to describe the dynamics of the population as a whole. No assumptions are made about the integrity of the stock and whether it can be considered a discrete unit. The only assumptions about immigration and emigration are those made at the boundaries of the model area, and these boundaries can, in principle, be placed to encompass the entire population.

In a spatially disaggregated model, mortality refers to the instantaneous rate of mortality

of the population *at a point*, not to the rate of mortality of the population as a whole. Mortality due to fishing varies over time and space from zero at times and places where no fleets are operating to over 0.5^{-mo} at times and places where fishing is intense. In contrast, natural mortality and fishing mortality in a unit stock model refer to the intantaneous rate of mortality *of the population as a whole*. Natural mortality estimated using the disaggregate model appears to be low in comparison to estimates from unit stock models. Higher rates of natural mortality estimated from unit stock models may be confounded with "mortality" due to emigration from the unit stock. In this sense, natural mortality is a measure of the departure from one of the major assumptions of unit stock models.

The analysis of fishery interaction concludes that purse seine fishing may have an adverse impact on pole and line fisheries for skipjack. This conclusion is based on the insupportable assumption that exploited fish populations approach equilibrium. Furthermore, all interannual and monthly variability has been averaged out, and the decrease is detectable only after a two year equilibration period. Whether changes on the order of 20% could be separated from interannual variability in real fisheries is unlikely. Verification of these hypothetical interactions using real data is essential before considering major changes in fishing policy.

Estimates of potential fishery interaction depend on the rate of natural mortality. In general, adverse effects of fisheries operating at a distance are less at higher levels of natural mortality. The relationship is not simple, however, because the estimated movement pattern also depends on natural mortality.

The advection-diffusion model appears to be a useful description of large-scale population movement. The parameters of the model can be estimated from existing data and the resulting empirical description of movement can be applied to predict the potential interactions between fisheries operating in different areas. Several improvements are desirable, however. The current parameterization in terms of regions and Seasons is too inflexible and ties behavior to specific times and places rather than to features of the environment. A more appropriate parameterization would express the movement parameters as functions of observable characteristics of the environment such as water temperature, depth, or oxygen concentration. Spatial gradients of these variables may also provide additional information from which to calculate model parameters.

The central role of natural mortality is obvious from this analysis. In almost all fisheries models, natural mortality is like a "residual", the quantity left over when mortality due to other causes (*i.e.*, fishing) has been counted. Further work on the causes and age dependence of mortality in tunas (and fish in general) is warranted.

The numerical approximations used to solve equation (2) employ a technique known as "upwind differencing". This approximation stabilizes the advective terms by introducing "numerical viscosity" into the approximation. The effect of this artificial diffusion seems to be low estimates of the parameter (D) in certain season-region strata (see Table 2). Preliminary attempts using alternative approximations show promising results.

The results of this analysis of large scale skipjack movement suggest several topics for future research. These topics range in generality from research on the management of specific fisheries to matters of fundamental importance in population dynamics.

The analysis of interaction suggest that pole and line fisheries for skipjack may have declined by as much as 20% in response to the growth of purse seine fisheries. This conclusion is based on the assumption that exploited populations reach equilibrium after a twenty year period of exploitation at a constant level of fishing mortality. Alternative models of population growth, movement, and exploitation that incorporate the high level of interannual and interdecadal variability, both in oceanic production systems and in social and economic

factors that drive fishing activities, are required. Preliminary efforts to create such models are currently being explored at the University of Hawaii and at the South Pacific Commission, but this challenging task will require more than a short term research and development effort.

The predicted reduction in pole and line yield must be considered to be a theoretical potential until empirical verification of the reduction is obtained. Attempts at verification through analysis of the historical record of catch and effort statistics have not yielded convincing evidence. Alternative methods of verification should be attempted. One alternative method is the use of what has become known as "adaptive management". Certain areas could be closed to purse seine fishing, but kept open to modest levels of pole and line fishing. Changes in pole and line catch rate inside the closed area could be compared with catch rates outside the closed area. An actual adaptive management experiment would require careful planning and a long-term commitment to catch rate monitoring in order to separate environmental effects from the effects of management policy.

Natural mortality emerges from the analysis of fisheries interaction as a critical process. Most fisheries models define natural mortality as mortality not attributable to fishing. Furthermore, natural mortality is usually assumed to be constant over the (exploited) life of the fish and throughout its range. In fact, we know very little about how fish, particularly tunas, die. It is generally recognized that predation is an important source of mortality. In some cases, emigration from the "stock" is recognized as a source of mortality. Senescence may also be important, but there is almost no information on the effects of ageng in fish. Research is required to improve our understanding of mortality in fish. A suite of model age-dependent mortality schedules, similar to those developed for human populations (Coale and Demeny, 1983), need to be developed for use in age-structured population models. A modest physiological research program on change in condition of tunas with age would greatly assist understanding senescence and could form a basis for developing age dependent mortality schedules.

Population models that explicitly include spatial variability and movement are clearly important in tuna fisheries. Several models of this type were discussed in the process of the Expert Consultation. In the future, these models will also be applied to other fisheries, for instance, to cod in the Atlantic ocean. However, more work is required to convince fisheries managers of the importance of spatially disaggregated models and to make such models more flexible and easily applied to different situations.

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A. APPENDIX — MODEL DESCRIPTION

A.1 Integrated Model of Movement and Population Dynamics

The model used in this analysis is an extended version of the model initially proposed by Sibert and Fournier (1994). Movement patterns were estimated by fitting a population dynamics model that explicitly incorporates movement to tag and recapture data. Let N_{xytr} symbolize the density of tagged skipjack at point (x, y) in the ocean at time t that comprised tag release cohort r. The aggregate density of tags from all cohorts released up to time t is given by

$$\tilde{N}_{xyt} = \sum_{r=1}^{R_t} N_{xytr} \tag{1}$$

The aggregated tag density is assumed to satisfy the following partial differential equation

$$\frac{\partial \tilde{N}}{\partial t} = \frac{\partial}{\partial x}(D\frac{\partial \tilde{N}}{\partial x}) + \frac{\partial}{\partial y}(D\frac{\partial \tilde{N}}{\partial y}) - \frac{\partial}{\partial x}(u\tilde{N}) - \frac{\partial}{\partial y}(v\tilde{N}) - Z\tilde{N} \tag{2}$$

Equation (2) partitions the rate of change of tag density into "dispersive" movements, "directed" movements, and mortality. The first two terms on the right hand side of equation (2) characterize dispersive movements in terms of a "diffusion" parameter D. The next two terms in equation (2) characterize "directed" movements in terms of two "advection" parameters (u, v) that describe eastward and northward directed movements. At any time t the movement parameters (u, v, D) may vary in space. The final term in equation (2) describes the loss of tagged fish at point (x, y) due to mortality. In this analysis the movement parameters (u, v, D) are interpreted to characterize the behavior of tagged skipjack at a point in space and time rather than to be features of the moving water in which the fish live. The form of the model is such that water movement could be easily added to the behavior parameters.

Mortality, Z, is separated into two components by

$$Z_{xyt} = M + \sum_{f} F_{xytf} \tag{3}$$

where F_{xytf} is the mortality due to fishing by fishing fleet f operating at point (x, y) during time t, and M is mortality due to other causes or "natural" mortality. Natural mortality is assumed be constant at all times and places. Fishing mortality is assumed to be a simple function of observed fishing effort

$$F_{xytf} = Q_f \times E_{xytf} \tag{4}$$

where E_{xytf} is the observed fishing effort of fleet f operating at point (x, y) during time t and Q_f is a fleet specific proportionality constant or catchability coefficient.

Boundary conditions and initial conditions are required to complete the specification of the model described by equation (2). Closed (reflective) boundaries are imposed:

$$\frac{\partial \tilde{N}}{\partial x} = 0; \qquad x = 0, x = X$$

$$\frac{\partial \tilde{N}}{\partial y} = 0; \qquad y = 0, y = Y$$

The obvious initial conditions for $\tilde{N}$ are

$$\tilde{N}_{xy0} = \begin{cases} N_{xy01}, & x = x_r \text{ and } y = y_r \\ 0, & \text{otherwise,} \end{cases}$$

where N_{xy01} is the number of tagged skipjack released at point (x_r, y_r) at time 0 in tag cohort 1.

The predicted number of skipjack tags returned during 1 month is given by

$$\widehat{C}_{xytf} = \beta_f \frac{F_{xytf}}{Z_{xyt}} \left(1 - \exp(-Z_{xyt}\Delta t) \right) \tilde{N}_{xyt} \tag{5}$$

where β_f is the reporting rate, i.e. the proportion of tags captured by fleet f returned with useable recapture information, Δt = 1 month, and $\tilde{N}$ satisfies equation (2) for month t.

A.2 Solution of PDE

Equation (2) is solved on a grid with a spatial resolution of 60 Nmi with a discrete time step. The finite differencing scheme and the solution methods were selected on the basis of numerical stability, convergence to a solution of equation (2) and robustness to coarse step sizes in both time and space. The second derivatives in the dispersive terms are approximated by three point central finite differences. The first derivatives in the directed terms are approximated by two point finite differences computed in the direction opposite the sign of the parameters (u, v), a scheme known as "upwind differencing" (Press et al., 1988). The following finite difference approximations are used:

$$\frac{\partial \tilde{N}}{\partial t} \sim \frac{\tilde{N}_{i,j,k+1} - \tilde{N}_{i,j,k}}{\Delta t}$$

$$\frac{\partial}{\partial x}(D\frac{\partial \tilde{N}}{\partial x}) \sim D_{i,j} \frac{\tilde{N}_{i-1,j,k+1} - 2\tilde{N}_{i,j,k+1} + \tilde{N}_{i+1,j,k+1}}{(\Delta x)^2} + \frac{(\tilde{N}_{i,j,k+1} - \tilde{N}_{i-1,j,k+1})(D_{i,j} - D_{i-1,j})}{(\Delta x)^2}$$

$$\frac{\partial}{\partial y}(D\frac{\partial \tilde{N}}{\partial y}) \sim D_{i,j} \frac{\tilde{N}_{i,j-1,k+1} - 2\tilde{N}_{i,j,k+1} + \tilde{N}_{i,j+1,k+1}}{(\Delta y)^2} + \frac{(\tilde{N}_{i,j,k+1} - \tilde{N}_{i,j-1,k+1})(D_{i,j} - D_{i,j-1})}{(\Delta y)^2}$$

$$\frac{\partial}{\partial x}(u\tilde{N}) \sim \begin{cases} u_{i,j} \dfrac{\tilde{N}_{i,j,k+1} - \tilde{N}_{i-1,j,k+1}}{\Delta x} + \tilde{N}_{i-1,j,k+1} \dfrac{u_{i,j} - u_{i-1,j}}{\Delta x}, & u_{i,j} > 0 \\ u_{i,j} \dfrac{\tilde{N}_{i+1,j,k+1} - \tilde{N}_{i,j,k+1}}{\Delta x} + \tilde{N}_{i+1,j,k+1} \dfrac{u_{i+1,j} - u_{i,j}}{\Delta x}, & u_{i,j} < 0 \end{cases}$$

$$\frac{\partial}{\partial y}(v\tilde{N}) \sim \begin{cases} v_{i,j} \dfrac{\tilde{N}_{i,j,k+1} - \tilde{N}_{i,j-1,k+1}}{\Delta y} + \tilde{N}_{i,j-1,k+1} \dfrac{v_{i,j} - v_{i,j-1}}{\Delta y}, & v_{i,j} > 0 \\ v_{i,j} \dfrac{\tilde{N}_{i,j+1,k+1} - \tilde{N}_{i,j,k+1}}{\Delta y} + \tilde{N}_{i,j+1,k+1} \dfrac{v_{i,j+1} - u_{i,j}}{\Delta y}, & v_{i,j} < 0 \end{cases}$$

In the subsequent discussion, the continuous subscripts x, y, t are replaced by their discrete equivalents i, j, k.

The "alternating direction implicit" method was used to solve the equations. This method is very robust and converges to a solution unconditionally for all steps sizes (Carnahan et al., 1969; Press et al., 1988). This method was selected because equation (2) is solved hundreds of times under the control of a numerical function minimiser. A method that is tolerant of large step sizes and possibly unrealistic parameters is therefore required. It was found in practice that a time step of $\frac{1}{4}$ months was sufficiently accurate.

A.3 Movement Pattern

Solution of equation (2) requires parameters to be specified at each grid point and at every time step. Regions and seasons are introduced to reduce the number of parameters that must be specified. A region is defined as a subdivision of the model area over which the movement parameters (u, v, D) are constant, and a season is defined as the period of time during with these parameters are constant. Let G_{ij} be a matrix that contains the region number for each model cell indexed by (i, j) and S_k be a vector that contains the season for each time step indexed by k. The model parameters are specified at each grid point by the following equations:

$$\begin{aligned} u_{ijk} &= \tilde{u}_{G_{ij}S_k} \\ v_{ijk} &= \tilde{v}_{G_{ij}S_k} \\ D_{ijk} &= \tilde{D}_{G_{ij}S_k} \end{aligned} \tag{6}$$

$\tilde{u}, \tilde{v}$, and $\tilde{D}$ are matrices of parameters to be specified. For a model with 10 regions and 2 seasons, there are 60 movement parameters so $\tilde{u}, \tilde{v}$, and $\tilde{D}$. are 2×10 matrices. These 60 parameters are used to specify values for u, v, and D in the 2100 points in the 60×35 model area used in the present analysis.

A.4 Parameter Estimation

Observed numbers of tag returns, C_{xytf}, are related to predicted numbers of tag returns, $\widehat{C}_{xytf}$, by a Poisson likelihood function.

$$L(\tilde{u}, \tilde{v}, \tilde{D}, Q, M, C_{xytf}) = \prod_{ijkf} \left[\frac{\widehat{C}_{xytf}^{C_{xytf}} e^{-\widehat{C}_{xytf}}}{C_{xytf}!} \right] \tag{7}$$

This function assumes that the predicted number of tag returns in each cell during one month is the expected value of a random variable with a Poisson distribution. This distribution is appropriate for an observation of a rare event such as the radioactive decay of an atom (Feller, 1968) or the recapture and return of a tagged skipjack.

Maximum likelihood parameter estimates are obtained by finding the values of the parameters that maximize equation (7). The maximization is accomplished by minimizing the negative log of equation (7) using a quasi-Newton numerical function minimiser which in turn depends on the gradient of partial derivative computed using adjoint functions (Griewank and Corliss, 1991).

$$\min_{\tilde{u}, \tilde{v}, \tilde{D}, Q, M} \quad -logL(\tilde{u}, \tilde{v}, \tilde{D}, Q, M, C_{xytf}) \tag{8}$$

The standard deviations of the parameter estimates are computed from the approximate Hessian matrix, the elements of which are

$$H_{ij} = \frac{\partial^2 L}{\partial \theta_i \partial \theta_j}$$

where θ_i and θ_j are any two model parameters. The variance of the parameter estimates are the diagonal elements of the inverse of the Hessian matrix $S = H^{-1}$ (Bard, 1974).

A.5 Fishery Simulation

For the purposes of analyzing fisheries interaction, the skipjack population density, P, is assumed to satisfy a PDE similar to that used to describe the dynamics of tagged skipjack

$$\frac{\partial P}{\partial t} = \frac{\partial}{\partial x}(D\frac{\partial P}{\partial x}) + \frac{\partial}{\partial y}(D\frac{\partial P}{\partial y}) - \frac{\partial}{\partial x}(uP) - \frac{\partial}{\partial y}(vP) - ZP + R \tag{9}$$

where R is the rate of recruitment of skipjack density at a point. The initial condition is $P = 0$ everywhere and the boundaries are closed. Equation (9) is solved by the same methods used to solve equation (2). Under some recruitment assumptions, the total skipjack density in the model area tends to a steady state. The simplest recruitment assumption is $R = 1^{-\text{mo}}$ everywhere. Under this assumption, a steady state is approached after approximately 120 months using parameters estimated from the RTTP data.

The predicted monthly skipjack catch at a point is given by

$$\hat{Y}_{xytf} = \frac{F_{xytf}}{Z_{xyt}}\left(1 - \exp(-Z_{xyt}\Delta t)\right)P_{xyt} \tag{10}$$

where $\hat{Y}_{xytf}$ is the catch by fleet f and P satisfies equation (9). The units of P and $\hat{Y}_{xytf}$ are arbitrary and determined by the units of R. Thus population density and yield are expressed in arbitrary skipjack recruitment units. In the interaction analysis, yield is normalized to remove the ambiguity imposed by the skipjack recruitment units.

A METHOD FOR ESTIMATING FISHERY INTERACTIONS FROM SOUTH PACIFIC ALBACORE CATCH-AT-LENGTH DATA USING THE SPARCLE MODEL

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ABSTRACT

A catch-at-length model based on a multiple fishery extension of the MULTIFAN length frequency analysis model is applied to fisheries catch-at-length data for South Pacific albacore. The model is used to estimate the catches which would be experienced in some fisheries if the catches from other fisheries had not occured.

1. INTRODUCTION

The primary motivation for the development of fisheries resource models is to obtain information useful for making policy decisions regarding future management of the fishery. An equally important motivation is the development of a tool for rigorously examining the data on which these decisions are based. Fisheries data usually come from a variety of different sources and are collected on different temporal and spatial scales of resolution. It is often not easy to determine whether these data sources are internally consistent and consistent with one another. A fisheries model can provide a yardstick with with to evaluate the consistency of data.

Much of the information used for managing exploited fish populations is derived at present from the analysis of fisheries catch-at-age data. These data, often combined with additional auxiliary data, are used in age-structured models to obtain estimates of stock size and exploitation rates. The catch-at-age estimates employed in these models are usually obtained by analyzing patterns in various body parts of individual fish, e.g., otoliths or fin ray sections. Fisheries catch-at-length data provide a convenient alternative for analysis by age-structured models. These data are much less costly to obtain and given the inaccurate nature of the age estimates for many fish species may actually provide better estimates of the relevant parameters in some situations.

We have employed an age-structured model based on the MULTIFAN system of converting length composition to age composition (Fournier et al., 1990) to analyze South Pacific albacore catch-at-length and effort data. This new model employs the same assumptions and estimation procedures as MULTIFAN for fitting the catch-at-length data. The main modifications to the model include the parameterization of the proportions at age in the catch via the catch equations, the ability of the model to deal with more than one catch-at-length sample (i.e., more than one fishery), and the inclusion of the total catch data (in this case, total numbers of fish) into the fitting procedure.

An important feature of our model is that it is fully integrated. Growth and age structure are estimated simultaneously with recruitment, selectivity, catchability and natural mortality. Another feature is that missing data and data of different temporal resolutions are allowable and are internally managed by the model. Also, various auxilliary data can be easily incorporated into assessments, as appropriate. Finally, we use more realistic parameterizations of fishing mortality than most previous statistical catch-at-age models. These include the possibility of estimating time series trends in catchability and selectivity.

The data structures and model assumptions necessary for dealing with arbitrary occurences of multiple fisheries are described Fournier et al. (in prep) to which the reader is referred for a more detailed descritption of the model, but a few equations useful for describing the calculations used in the fishery interaction estimation are presented.

The catch equations relate the numbers of fish in the population to the numbers of fish in the catch of the fisheries. Assume that there are a number of fisheries indexed by k, each of which occurs once per year. The relevant equations are:

$$C_{ijk} = \frac{F_{ijk}}{Z_{ij}}\left(1 - \exp(-Z_{ij})\right)N_{ij} \qquad 1 \le i \le n \quad 1 \le j \le r \tag{1.1}$$

$$N_{i+1,j+1} = \exp(-Z_{ij})N_{ij} \qquad 1 \le i < n \quad 1 \le j < r \tag{1.2}$$

$$N_{i+1,r} = \exp(-Z_{i,r-1})N_{i,r-1} + \exp(-Z_{ir})N_{ir} \qquad 1 \le i < n \tag{1.3}$$

$$Z_{ij} = \sum_k F_{ijk} + M_j \qquad 1 \le i \le n \quad 1 \le j \le r \tag{1.4}$$

where

n is the number of years of fishing,

r is the number of **distinct** age classes in the population (so that group r consist of all fish in age class r or older),

N_{ij} is the number of age class j fish in the population at the beginning of year i,

C_{ijk} is the number of age class j fish in the catch of fishery k in year i,

F_{ijk} is the instantaneous fishing mortality rate for fishery k for age class j fish in year i,

M_j is the instantaneous natural mortality rate for age class j fish,

Z_{ij} is the instantaneous total mortality rate for age class j fish in year i,

To estimate the interaction of a given fishery or group of fisheries on the other fisheries, the fishing mortality rate for that fishery is set equal to 0 and the C_{ijk} for the other fisheries are recalculated. Let $\tilde{C}_{ijk}$ denote the new catch estimates. The ratio of the new catch biomass to the old catch biomass assumed to be equal to

$$\sum_j \tilde{C}_{ijk}\mu_j^3 / \sum_j C_{ijk}\mu_j^3$$

where μ_j is the estimated mean length of age class j fish.

2. ORGANISATION OF THE DATA

The fishing activities had to be classified into fisheries, which is the fundamental model data structure. Fisheries should ideally consist of collections of similar vessels using similar fishing methods; we therefore defined a longline fishery, a driftnet fishery and two troll fisheries, one in New Zealand coastal waters and the other in the STCZ. The separation of troll into New Zealand (NZ) and STCZ fisheries was justified because of substantial differences in vessel sizes, technological backup and general fishing and searching techniques. Division of longline into several fisheries on the basis of area or targeting behaviour may also have been desirable, but we were prevented from exploring these options because much of the longline length frequency data were not available with sufficient resolution or accompanying information to allow this.

Catch, effort and length frequency data have been routinely collected from these fisheries over a long period of time by various fisheries agancies. Catch and effort data were compiled from fishermen's logbooks, while length frequency samples were taken in unloading ports and by at-sea observers. Generally, we did not have access to these original data, but were supplied with summaries aggregated by various area-time strata; the temporal resolution of the data varies from month to year. Also, there have been times when few or no length frequency data were collected for some fisheries and when no effort data were available. The data comprise 153 fishing incidents, beginning in 1962 and ending in 1992. The fishing period associated with each fishing incident depends on the temporal resolution of data available. Where this was greater than one month, it was assumed that the fishing incident occurred in the middle of the period.

3. ESTIMATION OF FISHERIES INTERACTIONS

To estimate the amount of fishery interaction we set the catch from a fishery or group of fisheries to zero and, using the parameter estimates from the model, calculated the increased catch for the other fisheries, assuming that the fishing mortality rates for these fisheries remained the same. Some remarks concerning the limitations of this approach are in order.

The model is not spatially disaggregated. It assumes that all fisheries are targeting the same group of fish. This is the price one must pay for using a model which does not require any information or assumptions about the movement of fish. If two fisheries are actually exploiting a common subgroup of the popualation this approach will tend to underestimate the amount of interaction between the two fisheries. On the other hand, if two fisheries are exploiting different subgroups of the population then this approach will tend to overestimate the extent of interaction.

4. RESULTS

The process of hypothesis testing and model selection is to that in MULTIFAN. Extra parameters associated with more complicated hypotheses are added to the model, and their effect on improving the goodness of fit is evaluated using standard significance tests. The process of selcting the "best" value for the natural mortality was more problematic.

To reduce the number of free parameters in the model it is often assumed that the instantaneous natural mortality is a constant, independent of the year and age. For South Pacific albacore, large changes in the proportion of males to females which occur over a small range in length indicate that older females may experience a much higher natural mortality rate than do older males. Since males and females are grouped in this analysis we cannot model this difference in mortality rates explicitly. Instead we have investigated the effect of imposing a higher instantaneous natural mortality rate for the older age classes. To incorporate the effect of larger natural mortaliy for females we set the instantaneous natural mortality rate 50 percent higher for the last three age classes. Two situations were considered — a natural mortality rate of 0.20 for the younger age classes and 0.30 for the older age classes, and a natural mortality rate of 0.40 for the younger age classes and 0.60 for the older age classes.

Figures 1 - 2 show the simulated results of setting the catch of fisheries 4 and 5 to 0. Figures 3 - 4 show the simulated results of setting the catch of fisheries 1 and 5 to 0. As one would expect, the effect is greater for a lower natural mortality rate. In any event, the maximum effect is only about 10%, so that one might conclude that there is no evidence of large amount of interaction for these data.

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Fournier, D.A., J. Hampton and J.R. Sibert. A length-based age-structured model for fisheries stock assessment, with application to South Pacific albacore *Thunnus Alalunga* in prep.

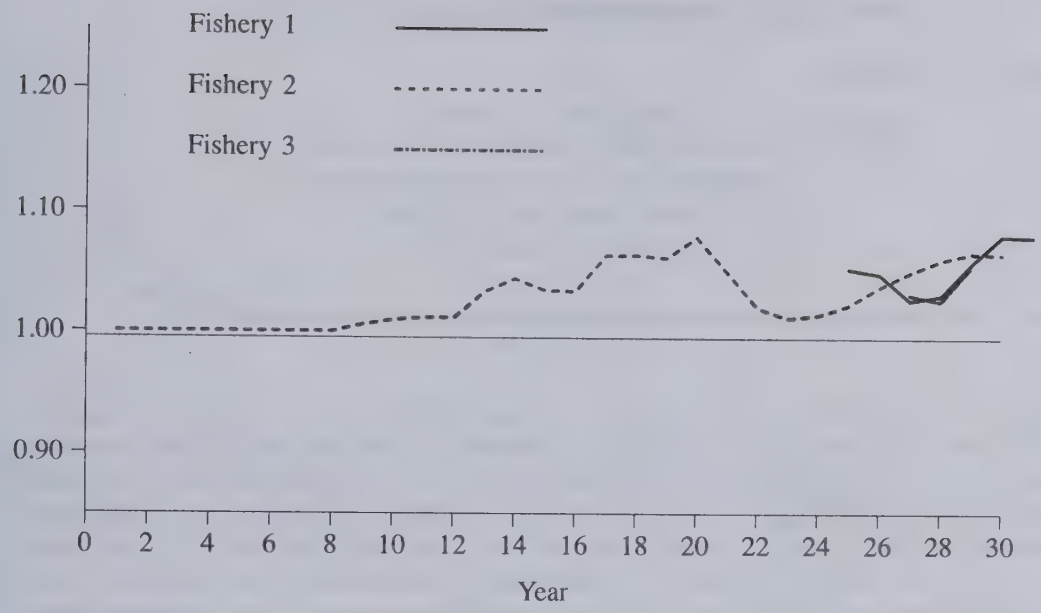

Figure 1. Relative catches in fisheries 1 through 3 when there is no catch in fisheries 4 and 5. Natural mortality = 0.2 on first 5 age classes and 0.3 on last 3 age classes.

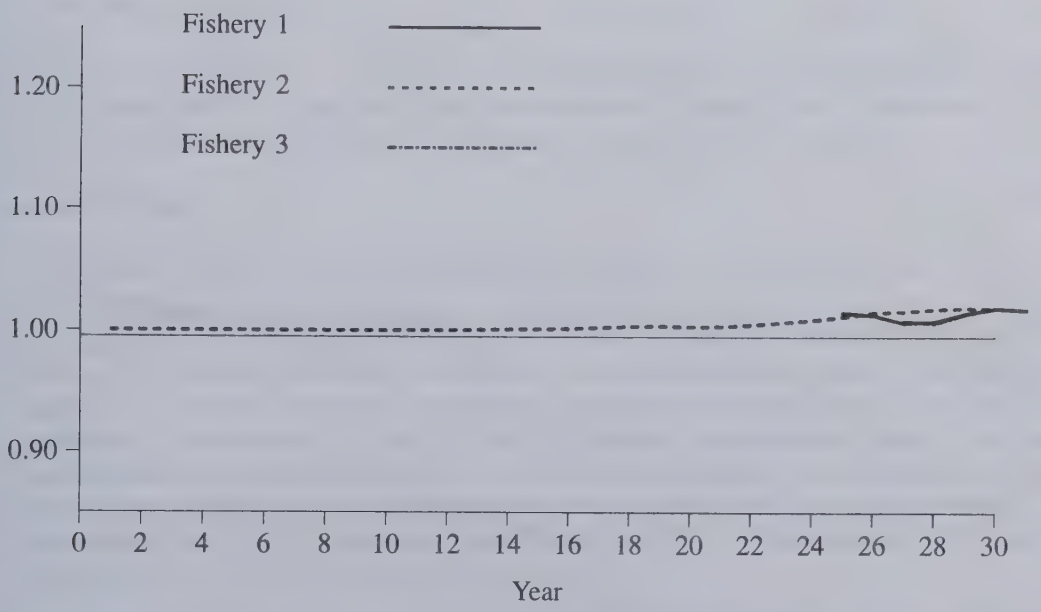

Figure 2. Relative catches in fisheries 1 through 3 when there is no catch in fisheries 4 and 5. Natural mortality = 0.4 on first 5 age classes and 0.6 on last 3 age classes.

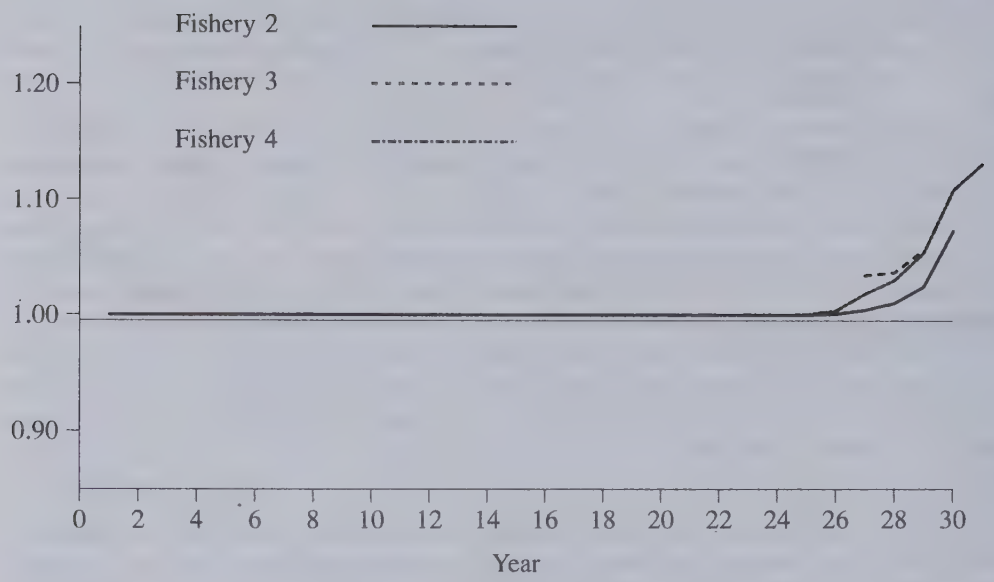

Figure 3. Relative catches in fisheries 2, 3, and 4 when there is no catch in fisheries 1 and 5. Natural mortality = 0.2 on first 5 age classes and 0.3 on last 3 age classes.

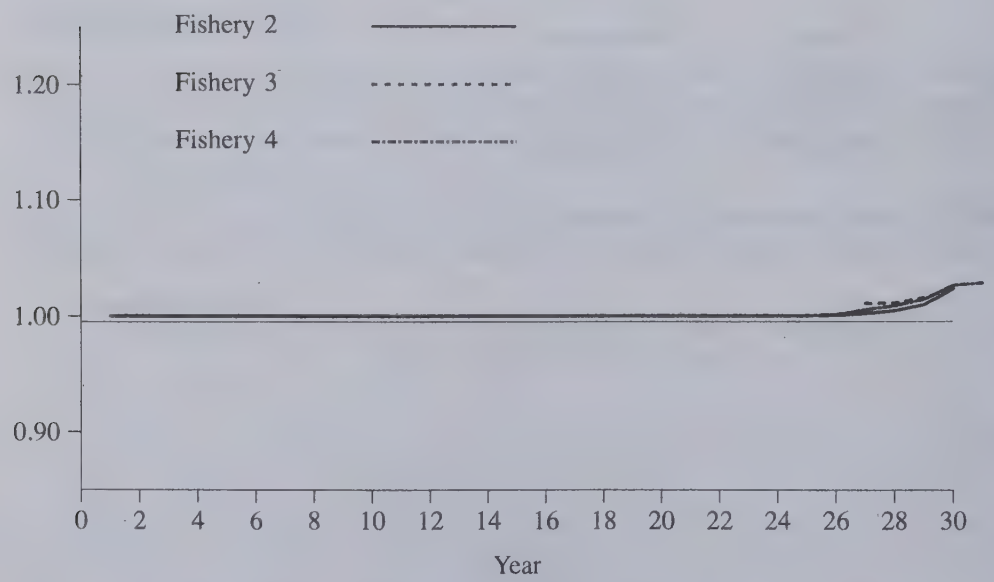

Figure 4. Relative catches in fisheries 2, 3, and 4 when there is no catch in fisheries 1 and 5. Natural mortality = 0.4 on first 5 age classes and 0.6 on last 3 age classes.

MOVEMENT OF LARGE BLUEFIN TUNA, *THUNNUS THYNNUS*, IN THE NORTH PACIFIC OCEAN, AS DETERMINED FROM THE JAPANESE LONGLINE FISHERY, AND IMPLICATIONS REGARDING INTERACTIONS BETWEEN THE FISHERIES OF THE WESTERN AND EASTERN PACIFIC OCEAN

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ABSTRACT

Japanese high-seas longline fishery data were used to plot the monthly distribution of catch and effort by 5-degree area. A scheme of weighting each 5-degree square was devised so that the location of catch or effort could be easily determined. The results show that there is a very pronounced pattern of movement in both the locations of the catch and the locations of the effort. Since the effort was more broadly distributed than the catches, it was concluded that large bluefin of the size caught by longliners generally follow a pattern of moving to the west in the spring and to the east in the fall, with most of the fish of this size staying in the northern Pacific Ocean. Occasionally, the eastern extension of the movement makes these large bluefin available to the purse seine fishery in the eastern Pacific Ocean.

1. INTRODUCTION

This study is based on catch and effort data for the Japanese high-seas longline fishery kindly made available to the staff of the Inter-American Tropical Tuna Commission (IATTC) by the National Research Institute of Far Seas Fisheries of Japan.

2. METHODS

The data utilized include summaries of catch by species, in numbers of fish, by year (1952-1986), month, and 5-degree area, and summaries of the effort, in number of hooks (not adjusted for any changes in efficiency over time), by year, month, and 5-degree area. The data for northern bluefin tuna (NBF) were extracted and summarized by month and 5-degree area. For the purpose of showing the distribution of catch by month, two time periods of 14 years each--1959 to 1972 and 1973 to 1986 were selected. Maps of the distributions of catches for each of the two time periods (Figures 1 to 12, top panel for the early period and bottom for the late period) were prepared. After examination of these distributions, a NBF core area was chosen (Figure 13). The core area contains 58 5-degree areas, all in the northern hemisphere. Let

C_{ijk} = NBF catch for year i, month j, and 5-degree area k,

E_{ijk} = number of hooks for year i, month j, and 5-degree area k,

and

U_{ijk} = catch per hook (CPUE) for year i, month j, and 5-degree area k,

$U_{ijk} = C_{ijk}/E_{ijk}$

where

i = 1, 2, ..., N; N = number of years,
j = 1, 2, ..., M; M = number of months, and
k = 1, 2, ..., L; L = number of 5-degree areas.

Total catches by year for the entire Pacific Ocean ($\Sigma\Sigma\Sigma$ C_{ijk}, N = 1, M = 12, L = 636) and for the core area ($\Sigma\Sigma\Sigma$ C_{ijk}, N = 1, M = 12, L = 58) were compiled (Table 1). The monthly totals, by year, of NBF catch, in numbers of fish, were calculated for the entire Pacific Ocean ($\Sigma\Sigma\Sigma$ C_{ijk}, N = 1, M = 1, L = 636) (Table 2) and for the core area ($\Sigma\Sigma\Sigma$ C_{ijk}, N = 1, M = 1, L = 58) (Table 3). The monthly totals, by year, of longline effort in thousands of hooks, were calculated for the core area ($\Sigma\Sigma\Sigma$ E_{ijk}, N = 1, M = 1, L = 58) (Table 4).

Within each year, a search was made to find the 5-degree area-month strata within the core area which contained the greatest catches and the greatest effort (Table 5). Similarly, the numbers of 5-degree area-month strata with catches of at least one NBF (Table 6), and the numbers of 5-degree area-month strata with effort of at least one hook (Table 7) were counted for each year.

For each longitudinal strip of 5 degrees, starting at the equator and going north or south, each 5-degree area going from 80°W to 80°E was given a number from 1 to 40. For each strip, the numbering starts with 1 in the east and goes sequentially to 40 in the west. The area covered by this numbering system has a total of 880 5-degree areas (22 5-degree strips with 40 5-degree areas per strip), with half the areas north of the equator. An index is formed by multiplying the number of NBF caught in a 5-degree area-month by the numerical value of that area and then summing over all area-months. This sum is divided by the sum of the catches to obtain a weighted estimate of the average index. Let

X_k = k = east-west value of area k; k = 1, 2, ..., 40, and

$V_{ij} = \Sigma\Sigma\ X_k C_{ijkl}/\Sigma\Sigma\ C_{ijkl}$; l = 1, 2, ..., 22 = east-west value for year i and month j.

This provides a numerical representation of the east-west origin of the catch; the higher the value, the more westerly the catch. These east-west values were computed for each month of each year of the 1952-1986 period for the entire Pacific Ocean (Figure 14) and for the NBF core area (Figure 15). Similar east-west values were calculated for effort within the entire Pacific Ocean (Figure 16), effort within the core area (Figure 17), and CPUE within the core area (Figure 18). The monthly values of catch (dotted lines) and effort (solid lines) for each year were plotted for the entire Pacific Ocean (Figure 19) and

for the NBF core area (Figure 20) to help determine if the east-west location of catch was influenced by the east-west location of effort.

3. RESULTS

3.1 Longline Catches

The core area usually contained more than 85% of the catch during the 1952-1971 period, but after that the percentages became more variable (Table 1). The data of Nakamura (1969) and Shingu et al. (1974) give the impression that most NBF caught by longline are between about 80 and 200 kg. The longline fishery appears to have made important contributions to the total catch during the early 1960s, but since about 1965 the contribution has been minor.

3.2 Movement

It appears that the large NBF caught by longliners concentrate on or near the spawning grounds in April through June and then move slightly to the north and substantially to the east (Figures 1 to 12, top and bottom, and Figure 17). The fish reach the central Pacific Ocean and beyond, especially during December through February. The distance between the average western location (say 25°N-130°E) in May and the average eastern location (say 32°N-172°E) in December-January is about 2.3 thousand nm (4.2 km). This means that the large NBF move about 383 nm (700 km) per month, or about 13 nm (23 km) per day. Of course, there is considerable variability in the data.

The monthly variation in the east-west location of the catch for the entire Pacific Ocean shows a consistent pattern (Figure 14), while the variation for Pacific-wide effort (Figure 16) is not so consistent. The effort is distributed farther to the east than the NBF catch for the Pacific-wide data, and the timing of the movements for catch (Figure 19, dotted line) differ from those of effort (Figure 19, solid line). However, the results are somewhat different when the analysis is confined to the core area. For the core area, the oscillation for catch (Figure 15) and effort (Figure 17) are much more nearly similar, with similar timing for catch (Figure 20, dotted line) as for effort (Figure 20, solid line). The locations of the greatest CPUEs (Figure 18) within the core area are very similar to the locations of the greatest catches (Figure 15). If the monthly indices for CPUEs are regressed against the indices for catch, the regression explains 89 percent of the variation in the CPUE data and the slope is not significantly different from 1. However, if a similar regression is done with effort, it explains only 51 percent of the variation in the effort data, and the slope is significantly different from 1. In the core area (on a month-by-month basis) the number of 5-degree areas with effort averaged between 11 and 51 (Table 7) with the overall average at about 30, while the number of 5-degree areas with catch averaged between 0 and 24 (Table 6) with the overall average at about 10. Therefore, within the core area, about two-thirds of the month-5 degree areas with effort produced no catch of NBF.

4. DISCUSSION

It is unfortunate that the results on movements must be tempered by the limitations of the data. Most of the NBF are caught from the core area, and within this area the effort

moves west to east and then back to the west on a regular cycle which is similar to that of the catch location, but more spread out. Since the distribution of effort is more spread out than the distribution of catch, there must be a high correlation between where the NBF are caught and where they actually are located. Also, the greatest CPUEs for NBF are in the same areas and times as the greatest catches. In other words, the effort seems to bracket the area where the NBF are being caught, with areas surrounding the catch areas having zero CPUE. Figures 21 and 22, which show the locations of catches and locations of areas with effort, but no catch, for two different months (May and December), clearly indicate that effort extends beyond the range of the catch, especially when the catches are from offshore during December. When the areas with catches were within the southwest part of the core area, there were still some effort to the east of where the NBF were being caught, but not much. However, when the main areas with catches were in the northeast part of the core area, there were still large amounts of effort in the western part with small catches of NBF.

Large NBF, similar in size to those caught by longliners, were caught by purse seiners in the eastern Pacific during November and December of 1988 (Foreman and Ishizuka, 1990). These fish may have appeared in the eastern Pacific during the fall of 1988 because they were distributed further to the east than is usually the case. It does indicate there is some possibility that the large NBF usually exploited by longliners in the central Pacific during December to February could be taken by purse seiners operating in the eastern Pacific.

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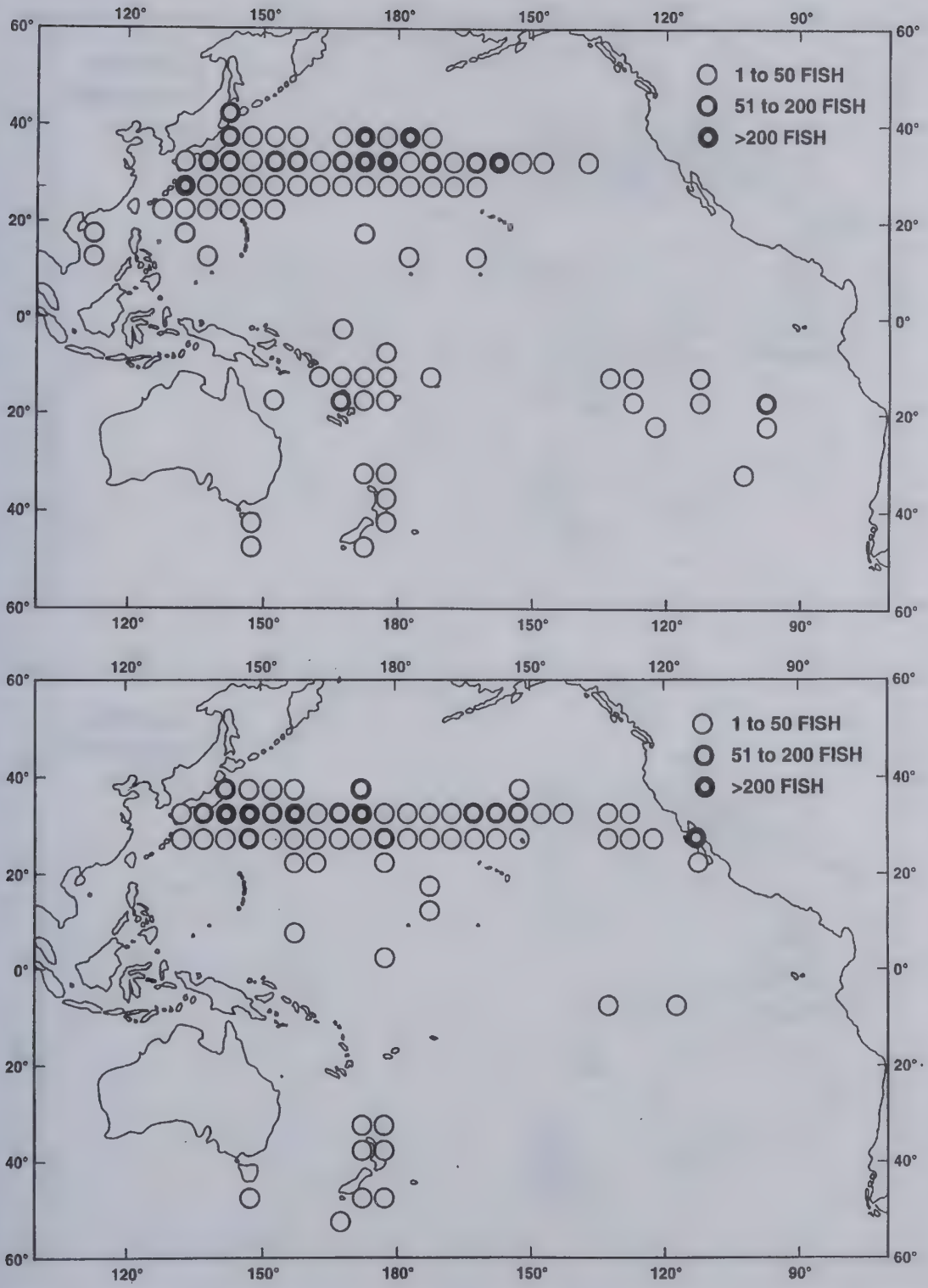

Figure 1. January distribution of Japanese longline catches of NBF, summed over two time periods of 14 years each (top is 1959 to 1972 and bottom is 1973 to 1986).

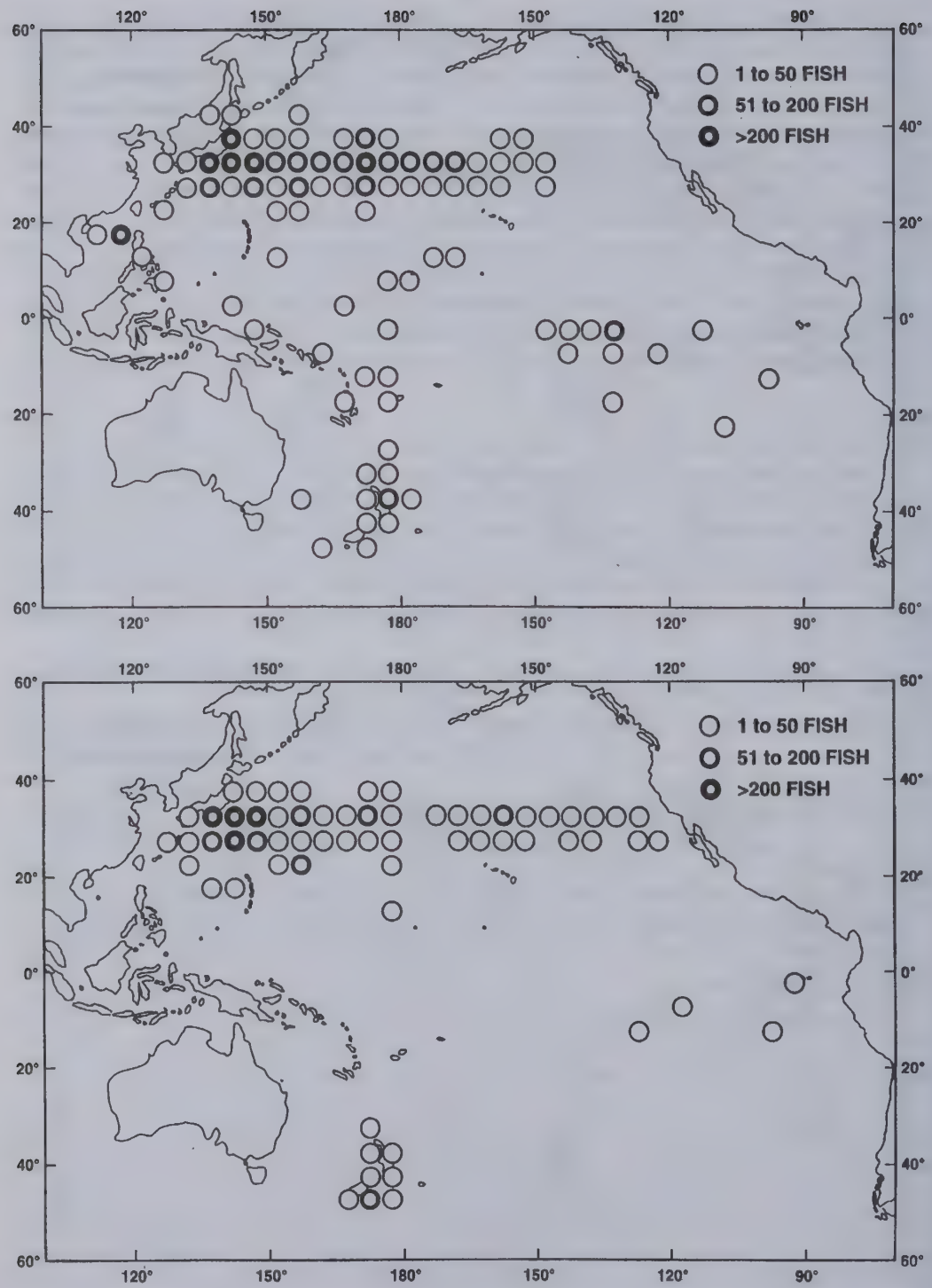

Figure 2. February distribution of Japanese longline catches of NBF, summed over two time periods of 14 years each (top is 1959 to 1972 and bottom is 1973 to 1986).

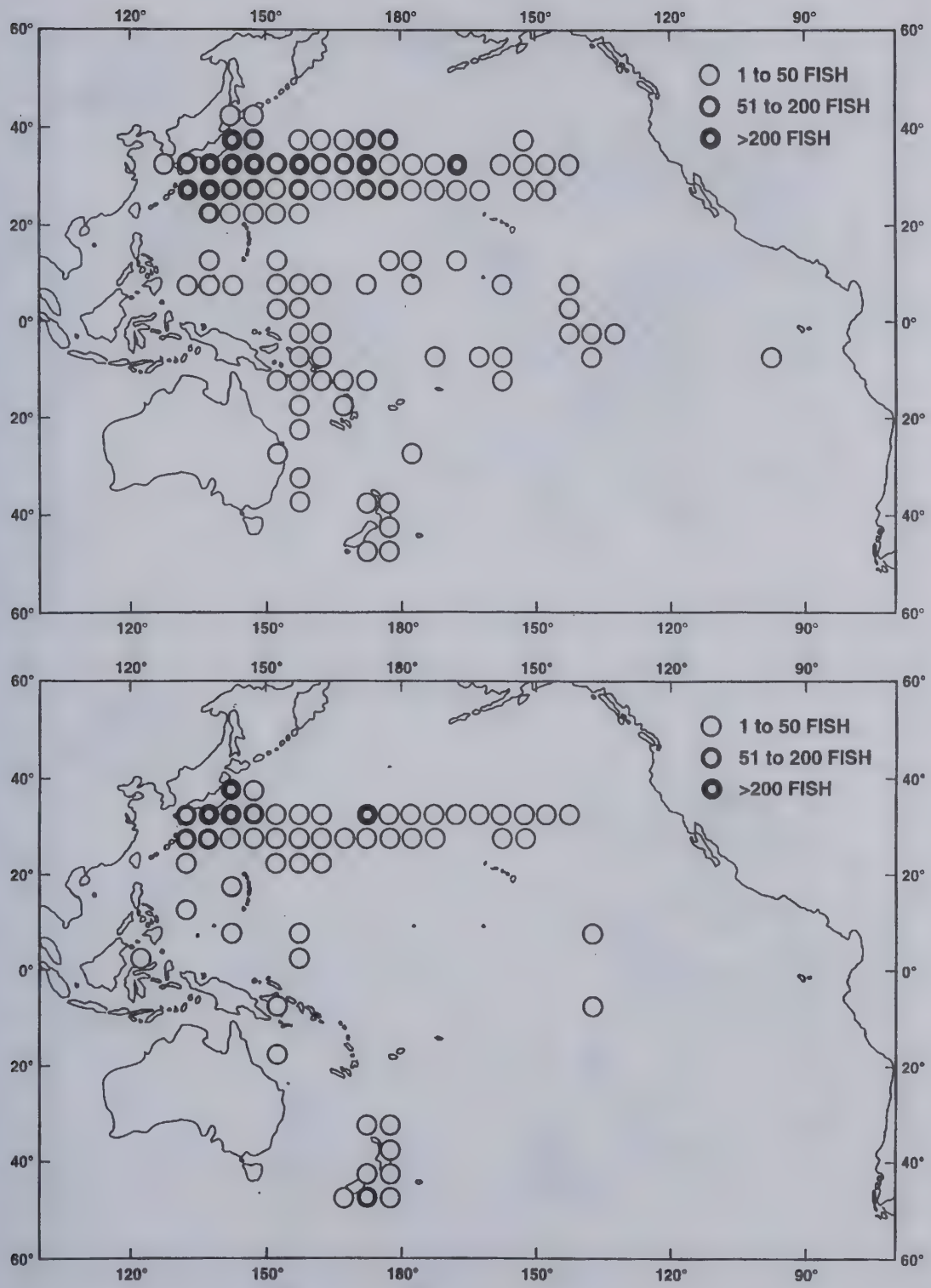

Figure 3. March distribution of Japanese longline catches of NBF, summed over two time periods of 14 years each (top is 1959 to 1972 and bottom is 1973 to 1986).

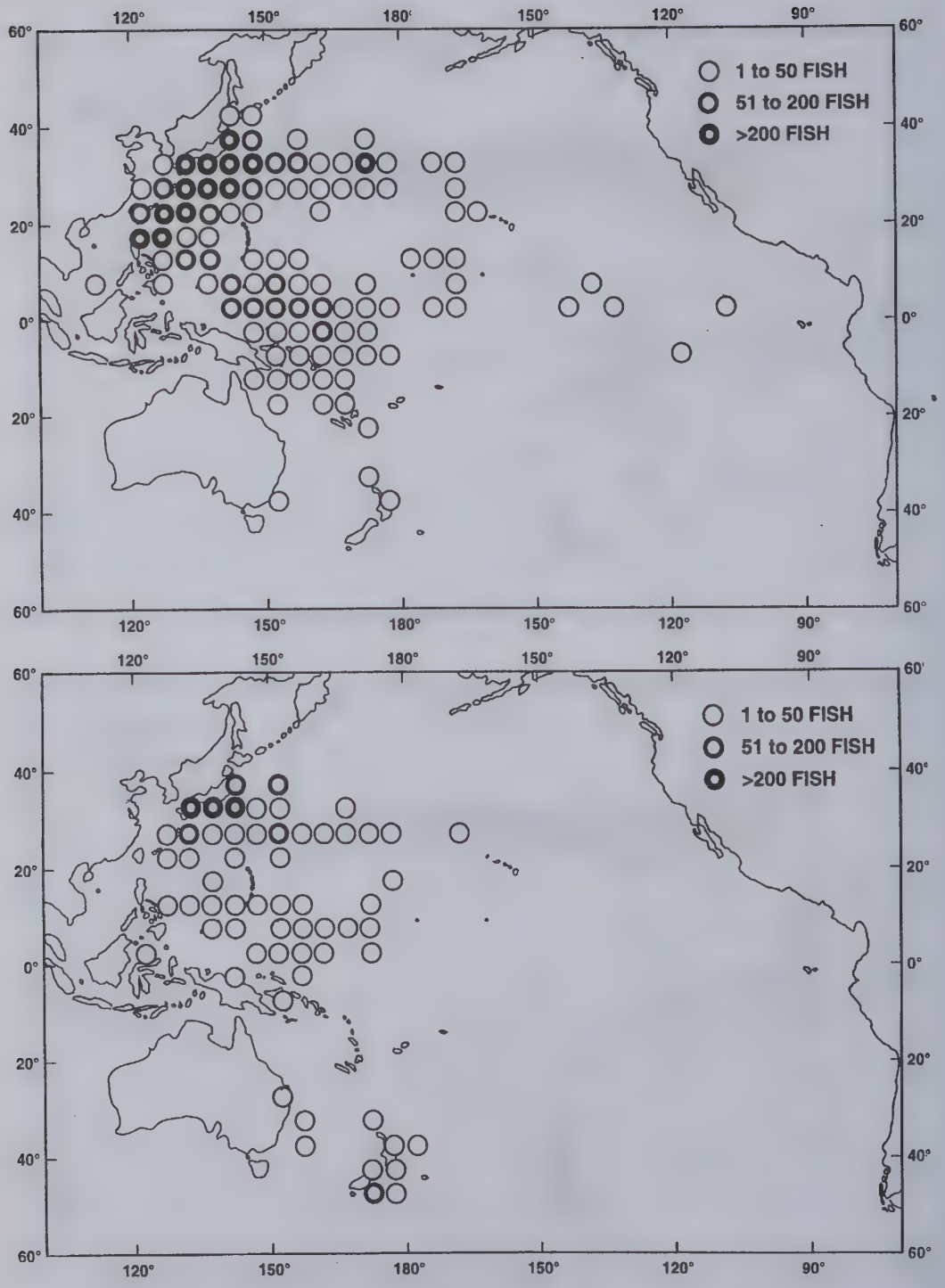

Figure 4. April distribution of Japanese longline catches of NBF, summed over two time periods of 14 years each (top is 1959 to 1972 and bottom is 1973 to 1986).

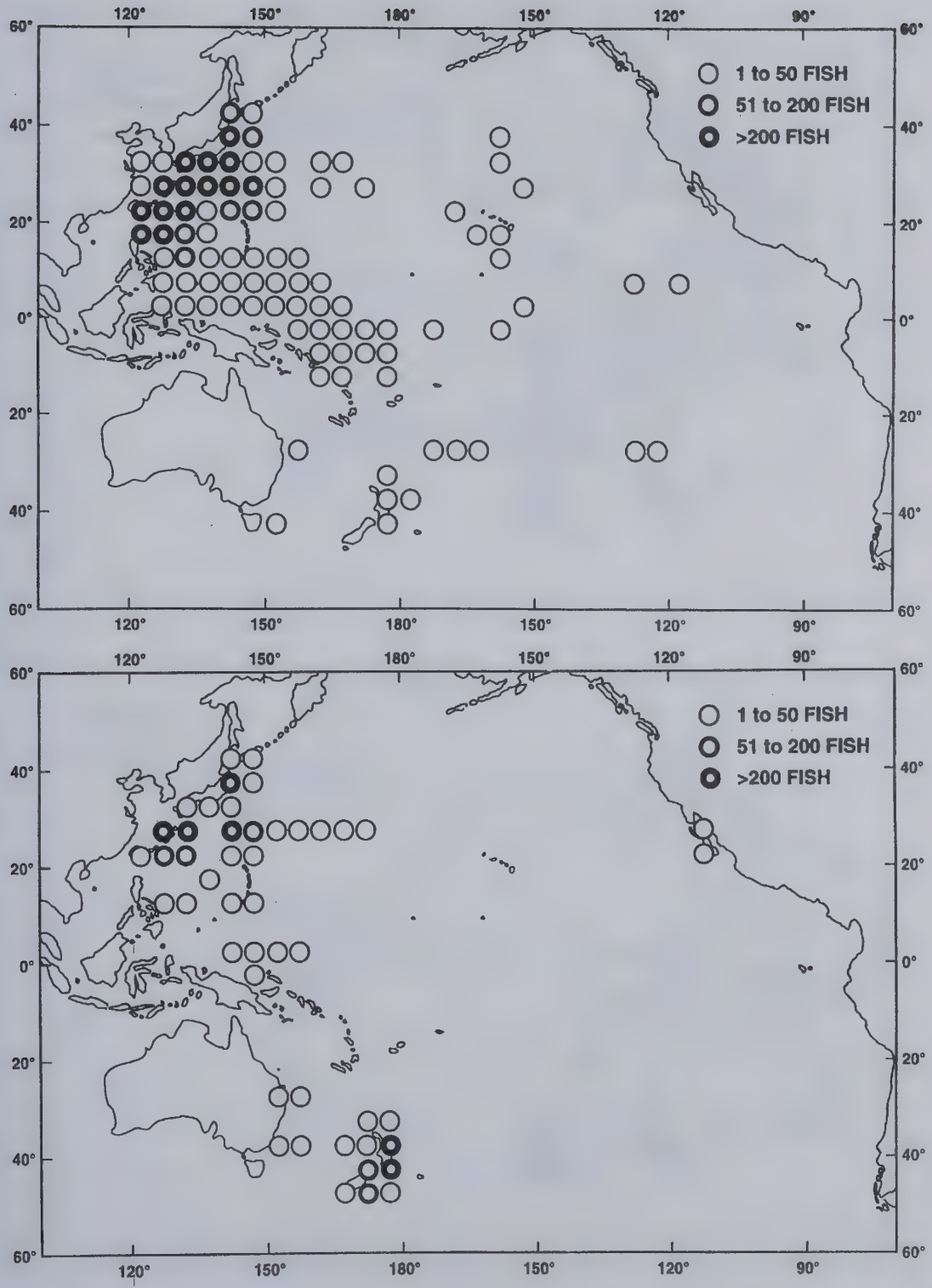

Figure 5. May distribution of Japanese longline catches of NBF, summed over two time periods of 14 years each (top is 1959 to 1972 and bottom is 1973 to 1986).

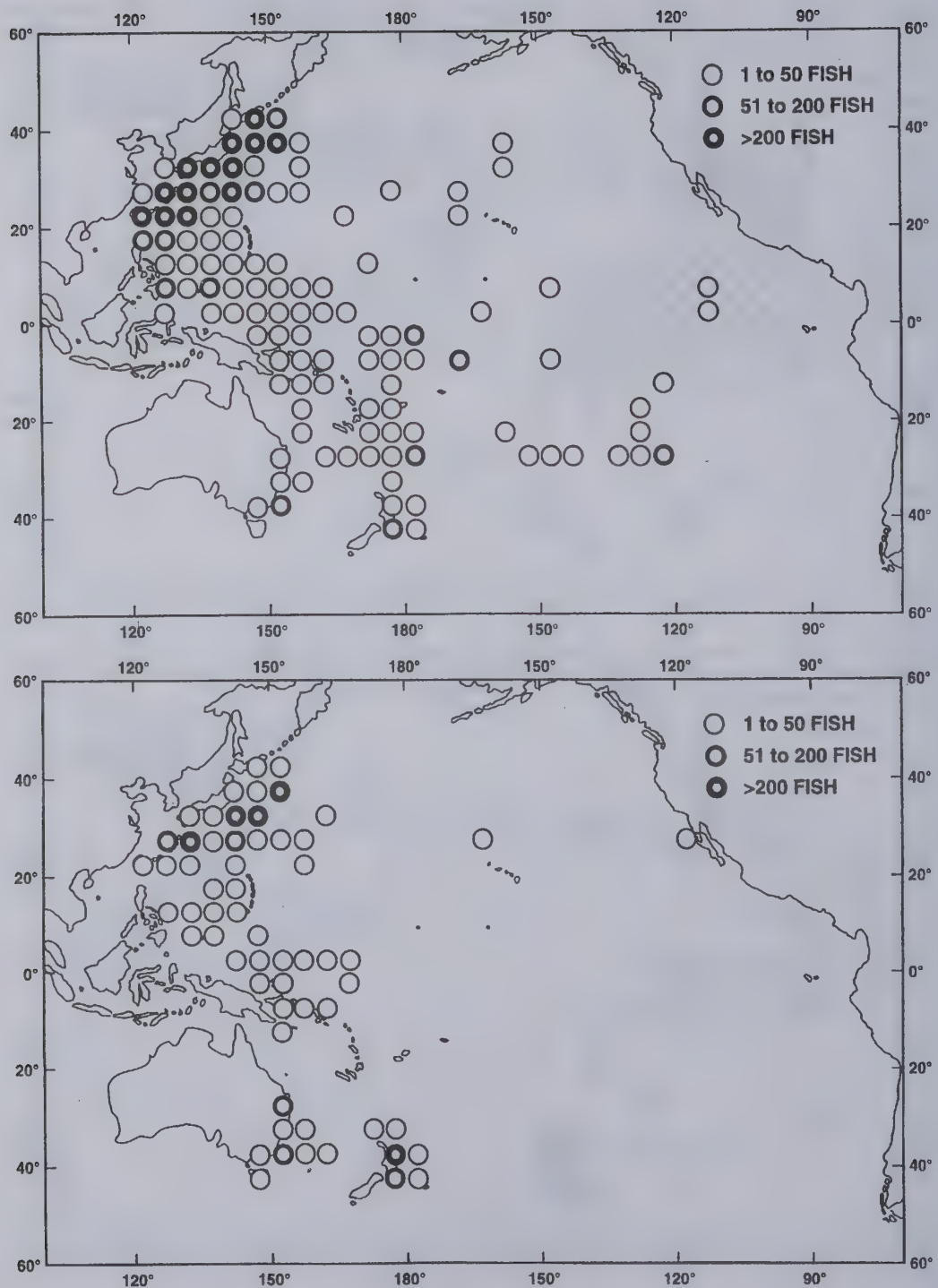

Figure 6. June distribution of Japanese longline catches of NBF, summed over two time periods of 14 years each (top is 1959 to 1972 and bottom is 1973 to 1986).

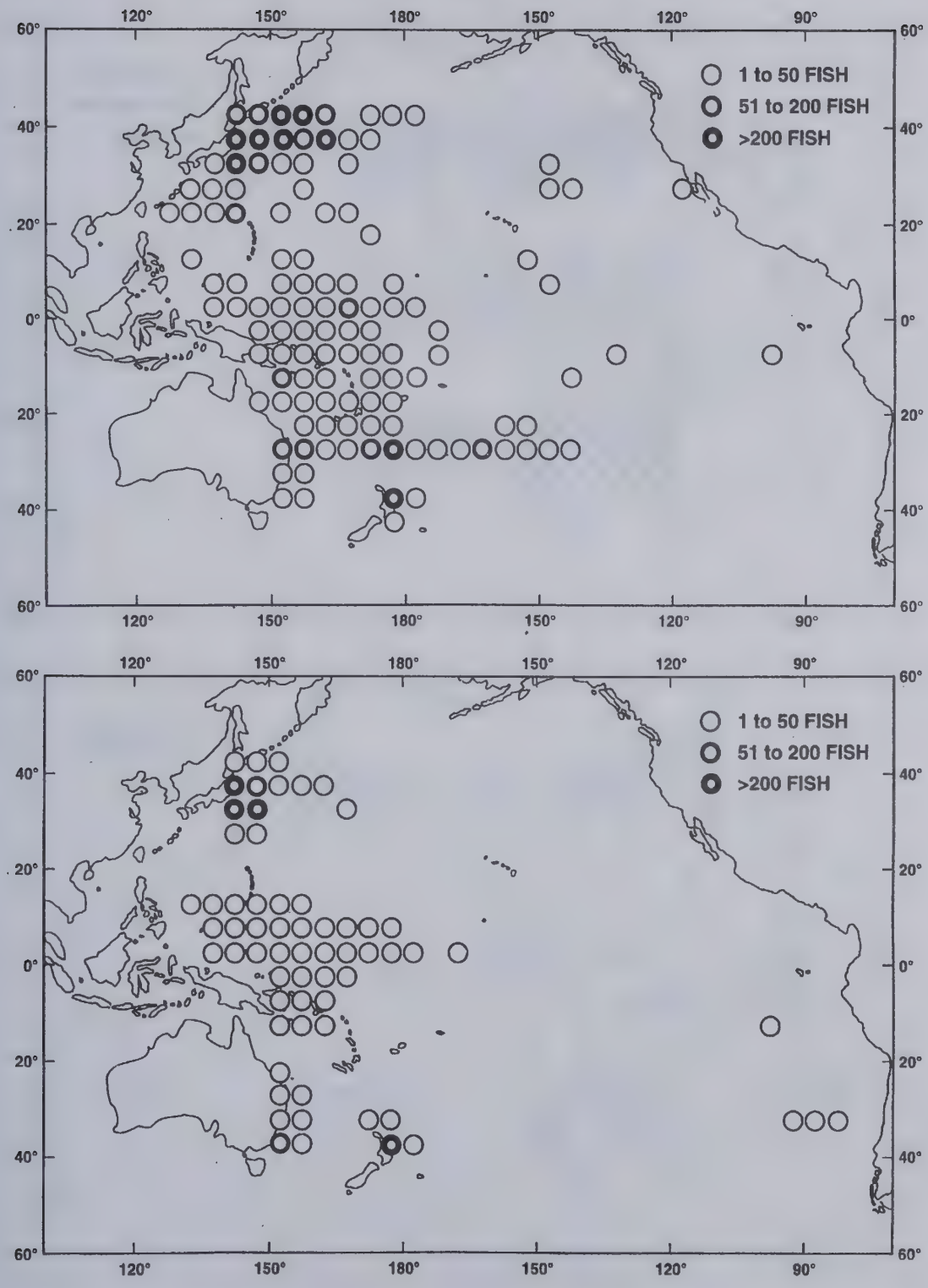

Figure 7. July distribution of Japanese longline catches of NBF, summed over two time periods of 14 years each (top is 1959 to 1972 and bottom is 1973 to 1986).

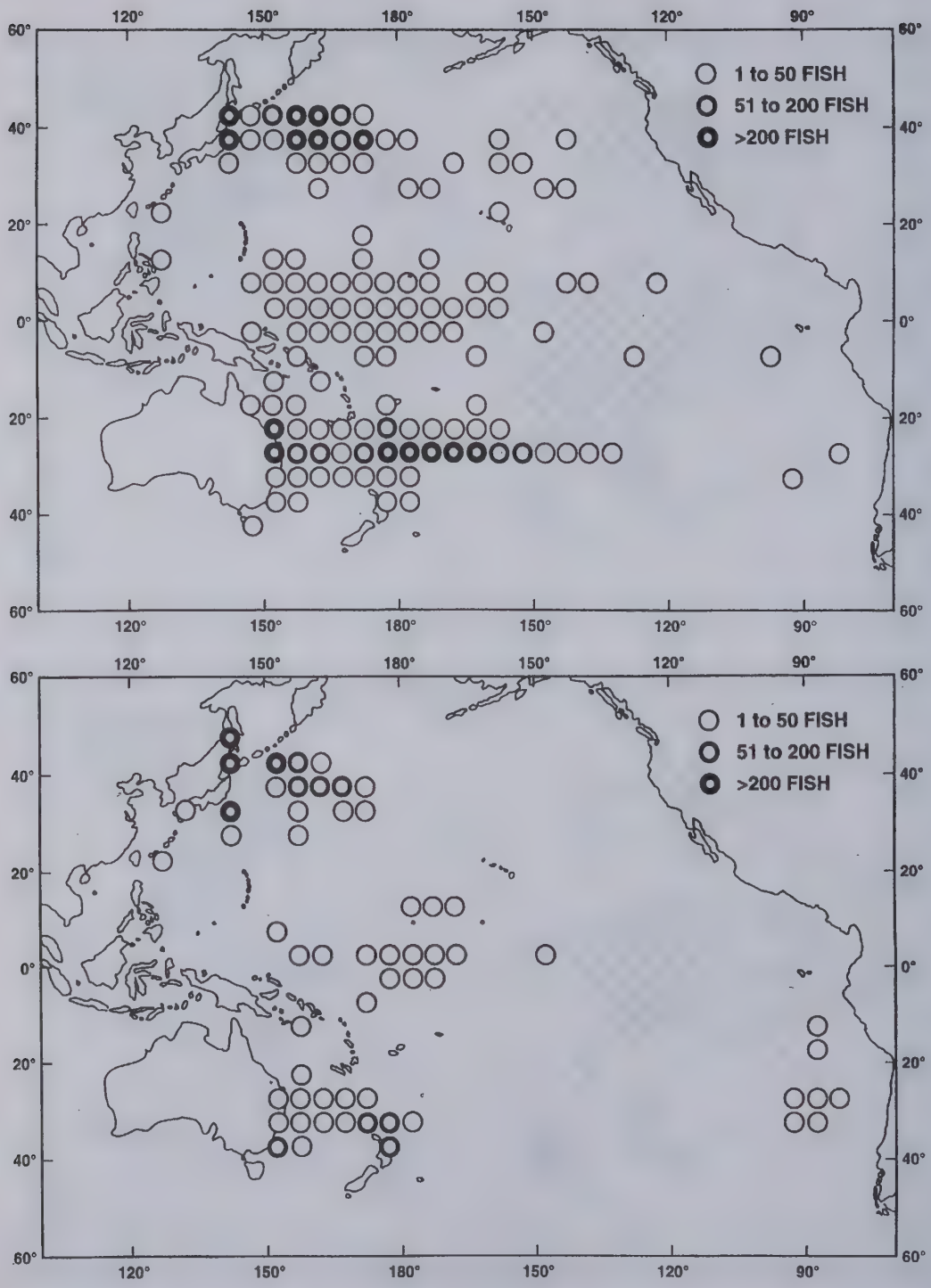

Figure 8. August distribution of Japanese longline catches of NBF, summed over two time periods of 14 years each (top is 1959 to 1972 and bottom is 1973 to 1986).

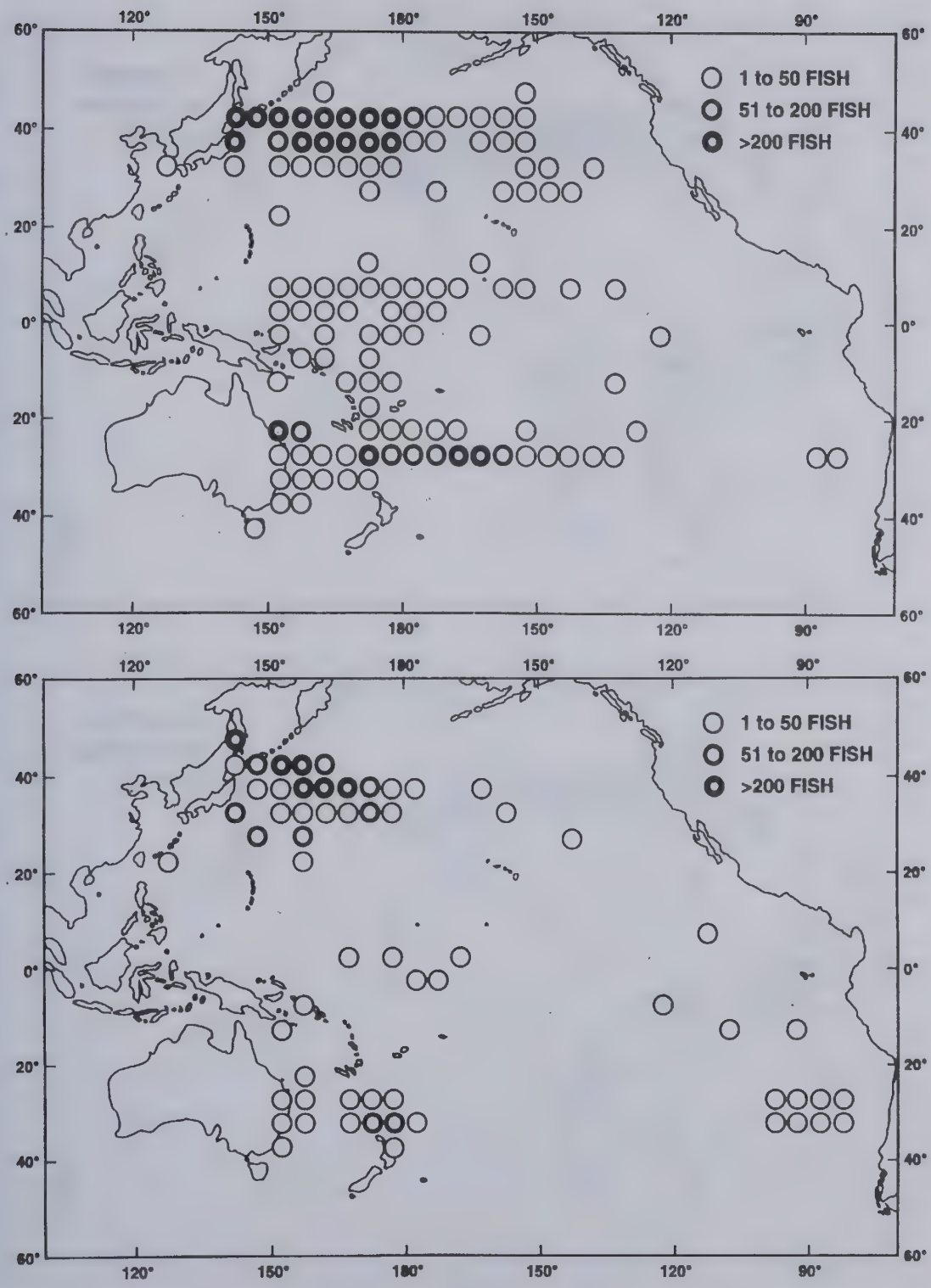

Figure 9. September distribution of Japanese longline catches of NBF, summed over two time periods of 14 years each (top is 1959 to 1972 and bottom is 1973 to 1986).

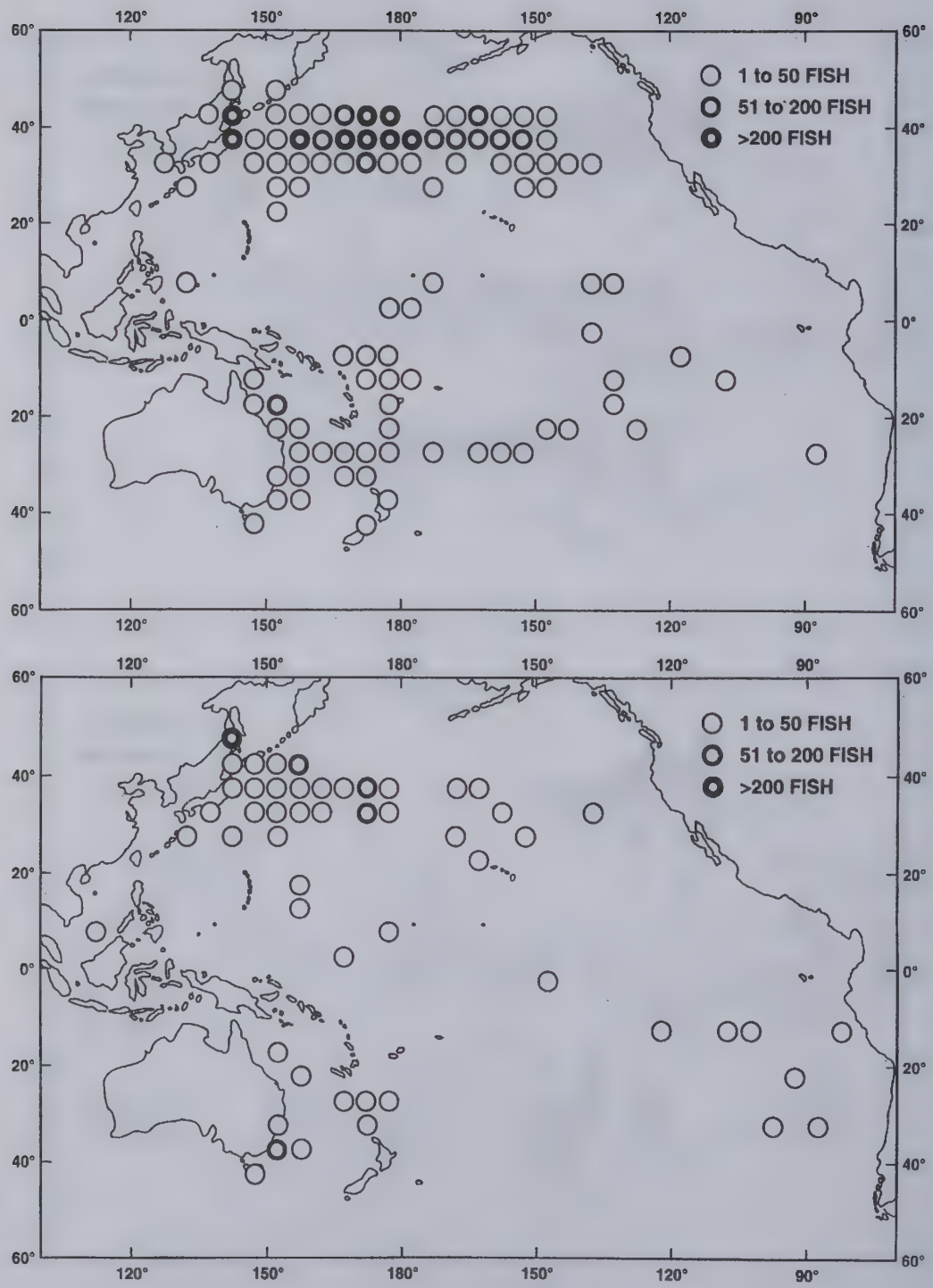

Figure 10. October distribution of Japanese longline catches of NBF, summed over two time periods of 14 years each (top is 1959 to 1972 and bottom is 1973 to 1986).

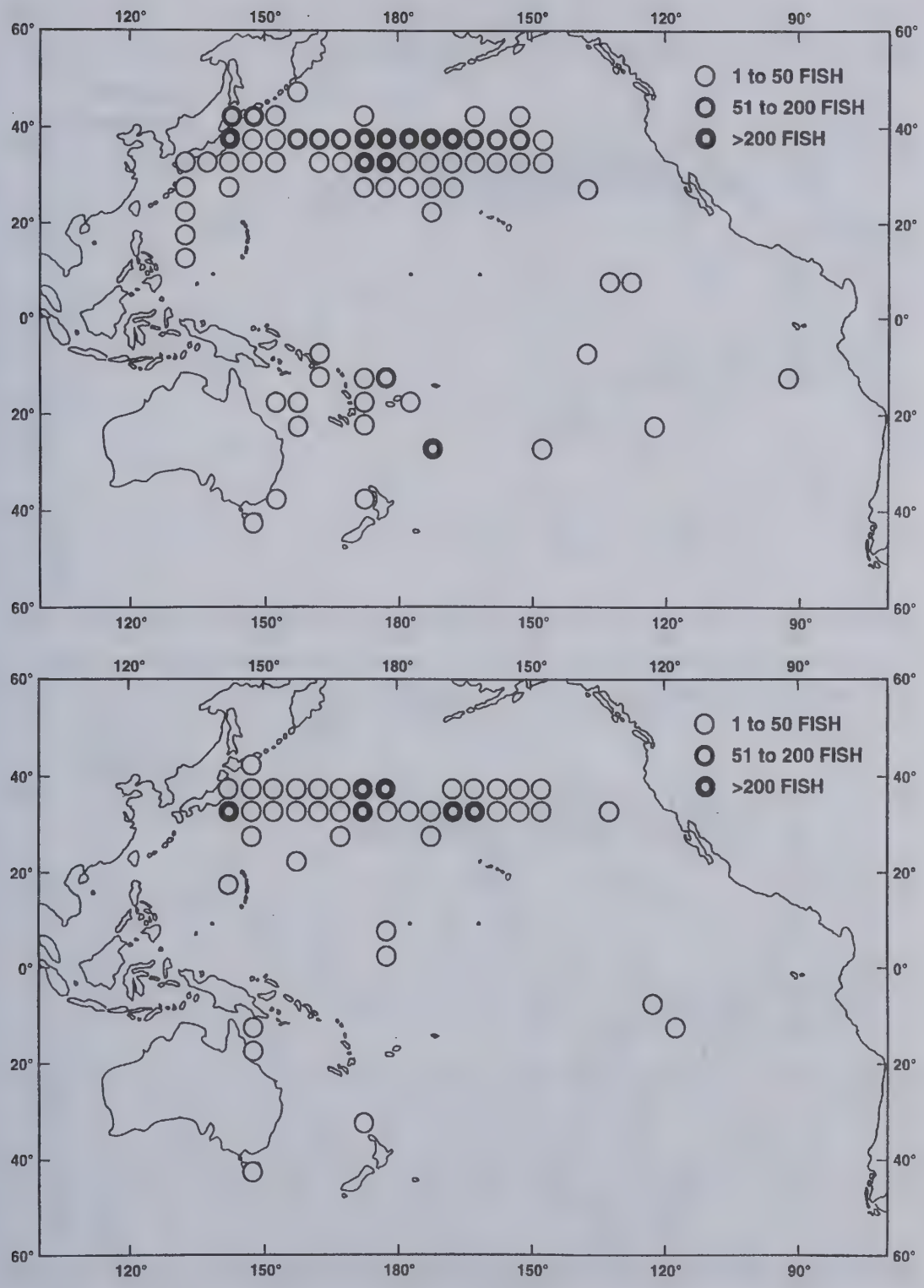

Figure 11. November distribution of Japanese longline catches of NBF, summed over two time periods of 14 years each (top is 1959 to 1972 and bottom is 1973 to 1986).

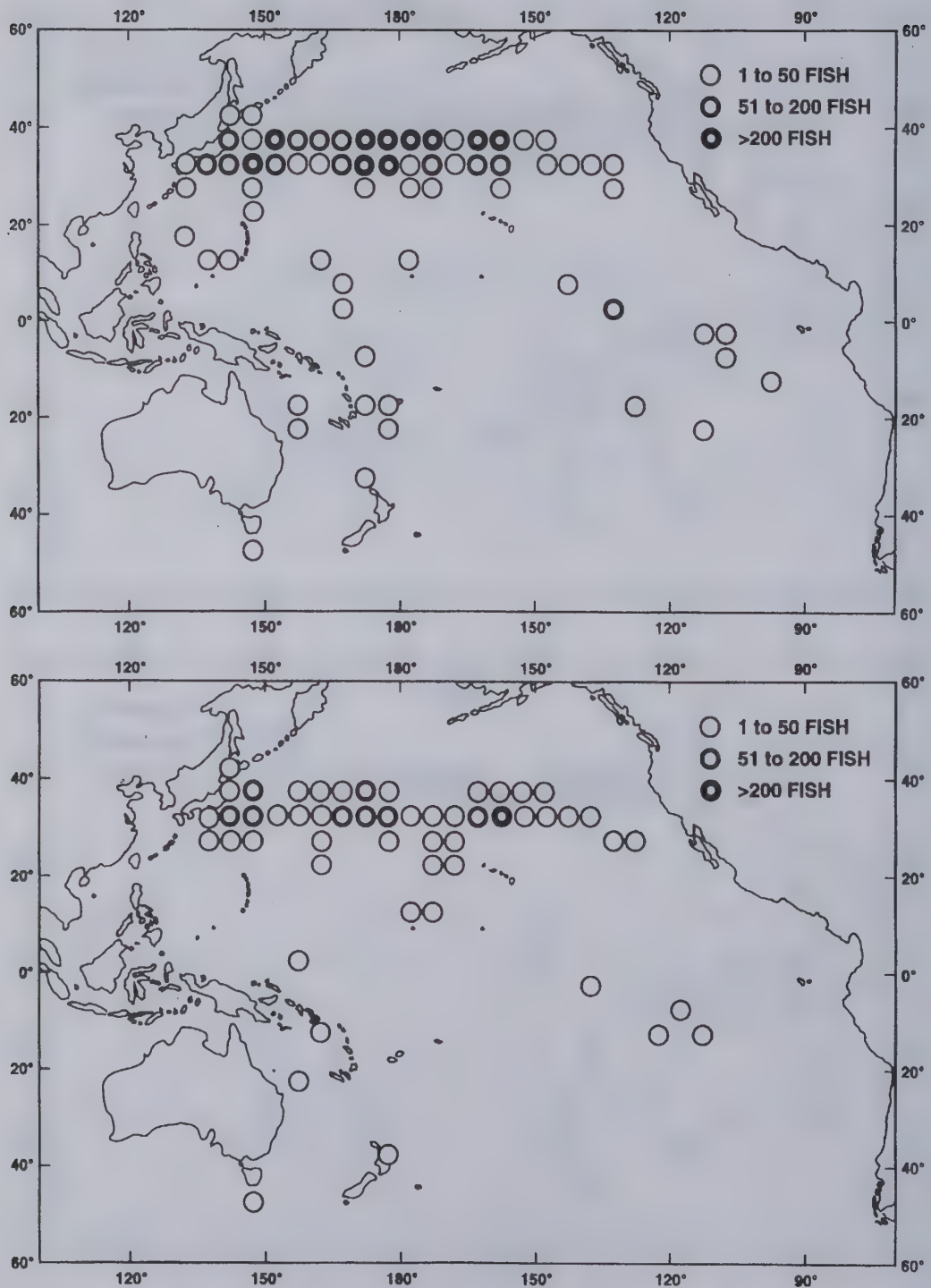

Figure 12. December distribution of Japanese longline catches of NBF, summed over two time periods of 14 years each (top is 1959 to 1972 and bottom is 1973 to 1986).

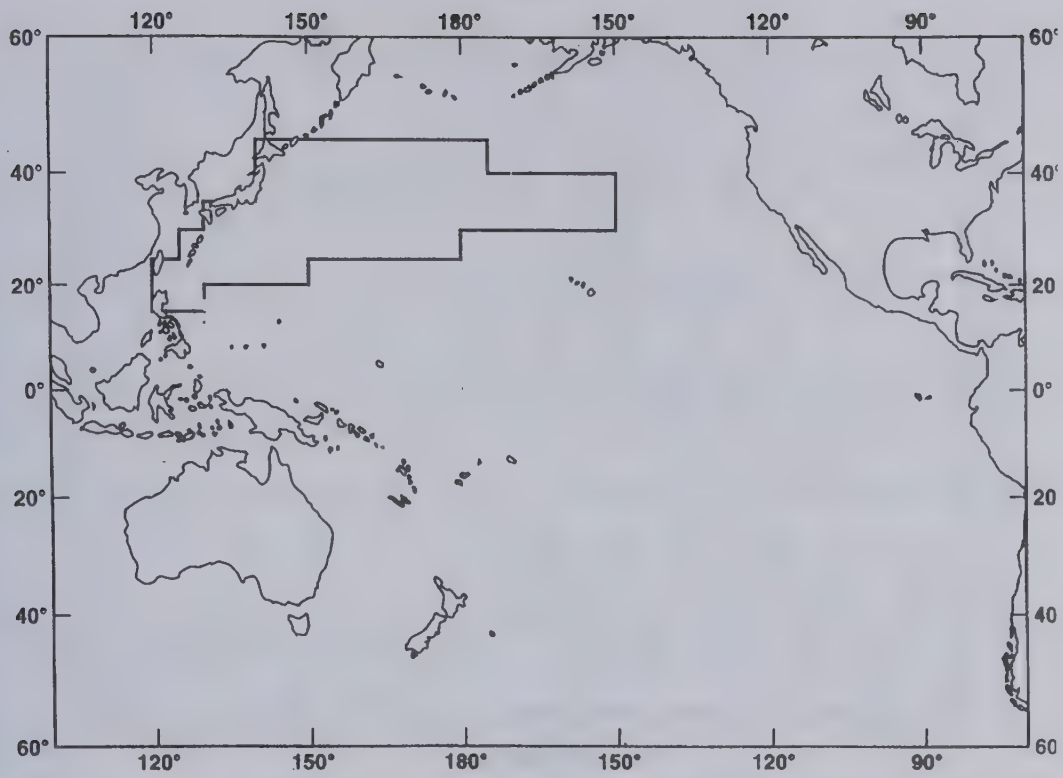

Figure 13. Japanese longline fishery core area for NBF. Total area contains 58 5-degree areas.

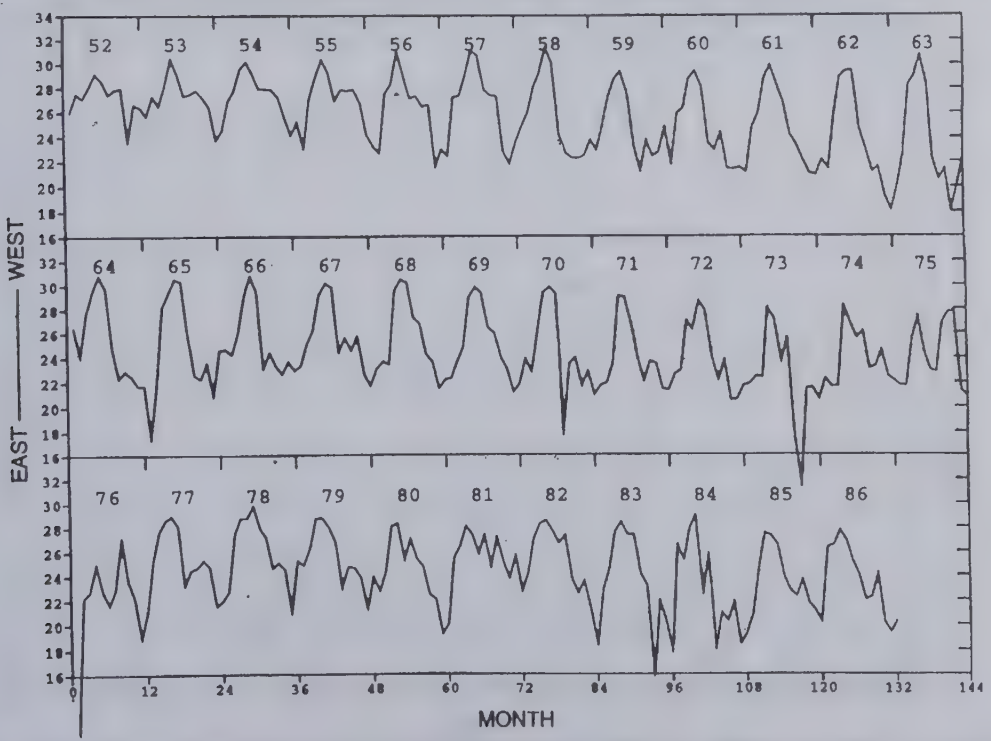

Figure 14. Japanese longline monthly index of east-west location for NBF catches from the entire Pacific Ocean. The greater the number, the farther west the NBF were captured, on average.

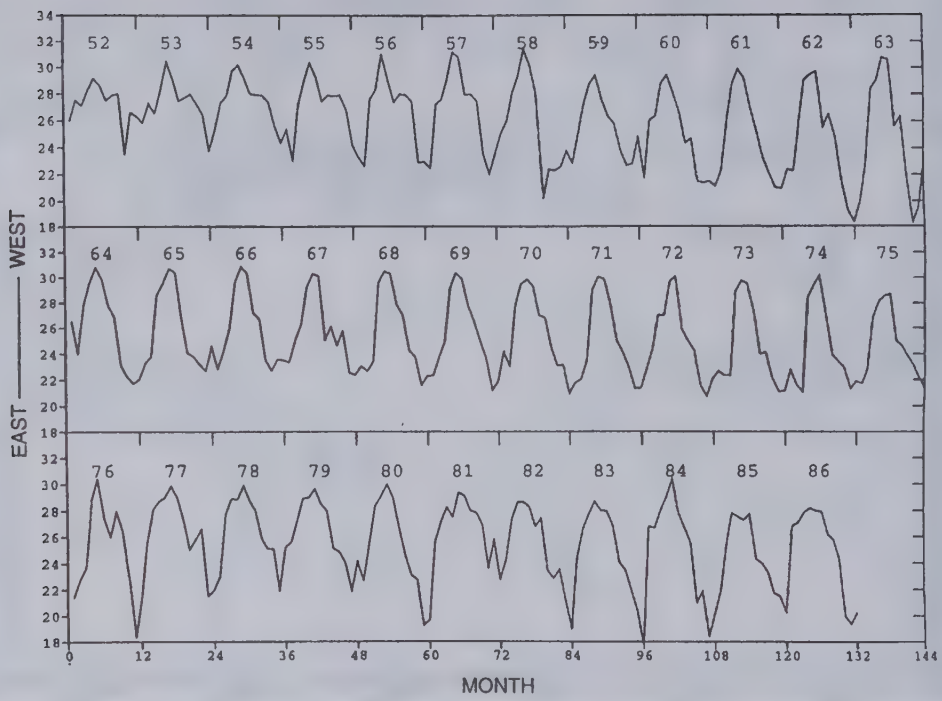

Figure 15. Japanese longline monthly index of east-west location for NBF catches from the core area. The greater the number, the farther west the NBF were captured, on average.

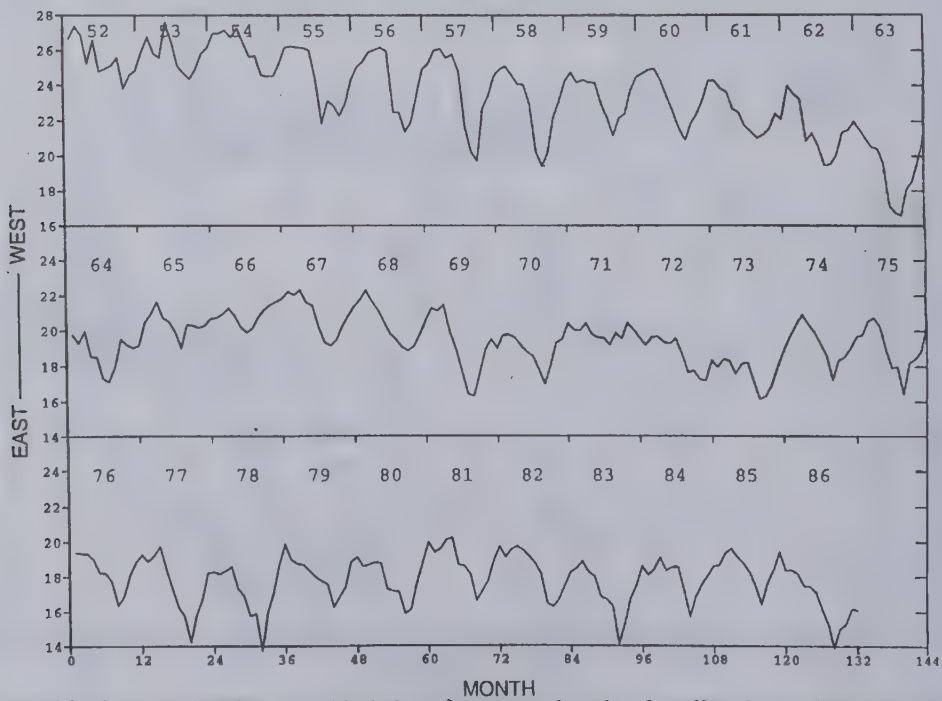

Figure 16. Japanese longline monthly index of east-west location for effort from within the entire Pacific Ocean. The greater the number, the farther west the effort, on average.

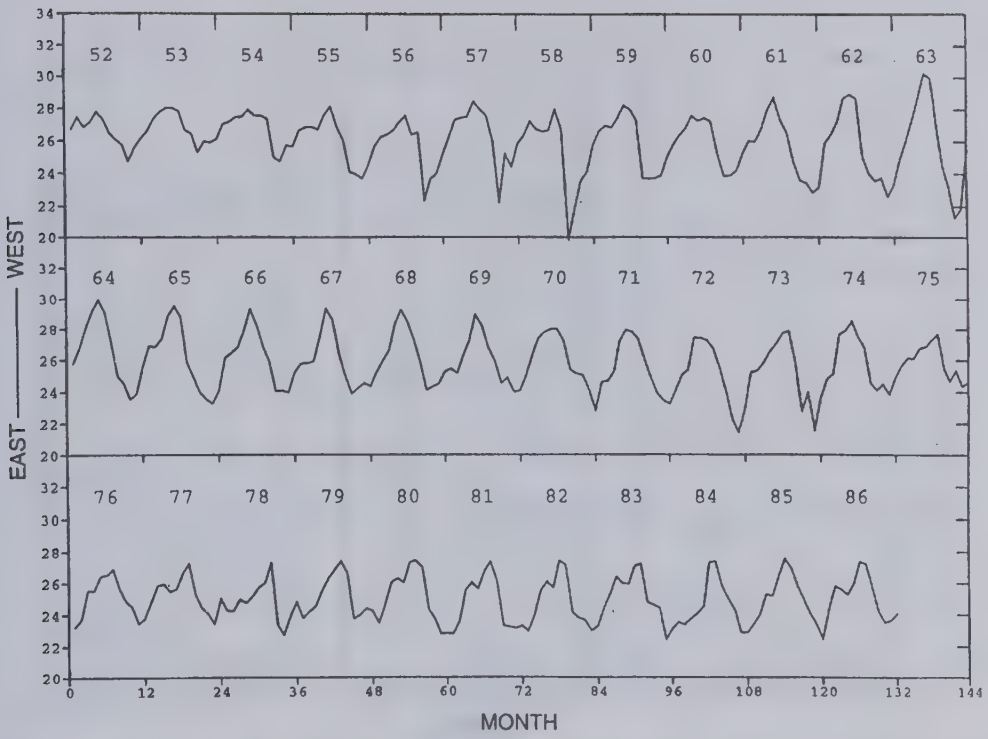

Figure 17. Japanese longline monthly index of east-west location for effort from within the core area. The greater the number, the farther west the effort, on average.

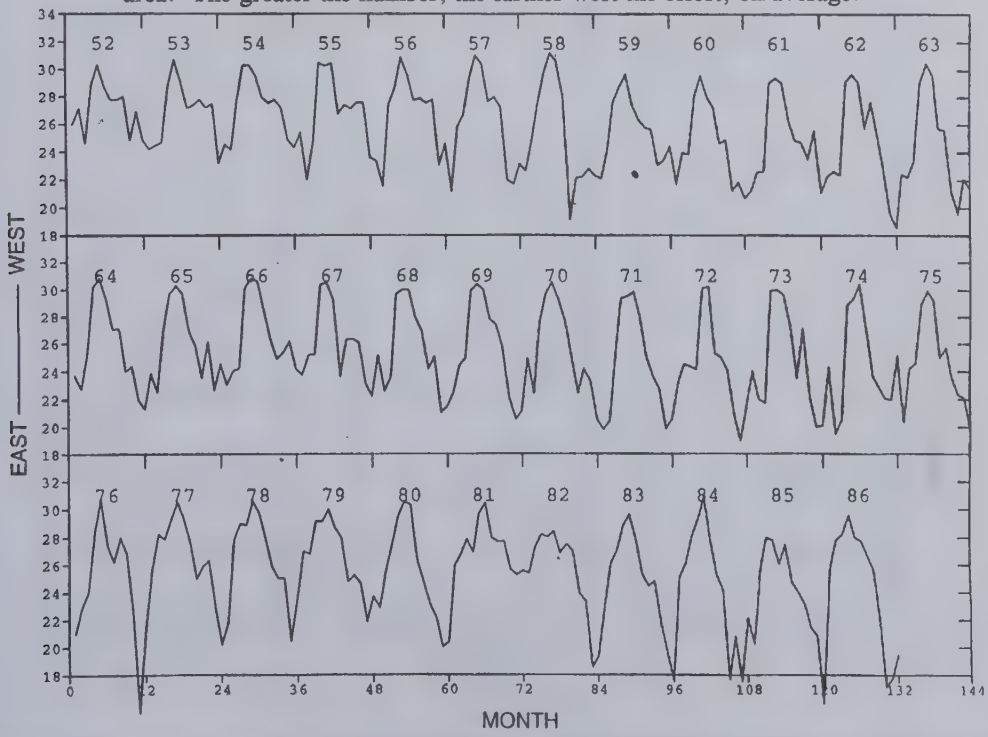

Figure 18. Japanese longline monthly index of east-west location for CPUEs from within the core area. The greater the number, the farther west the greatest CPUE, on average.

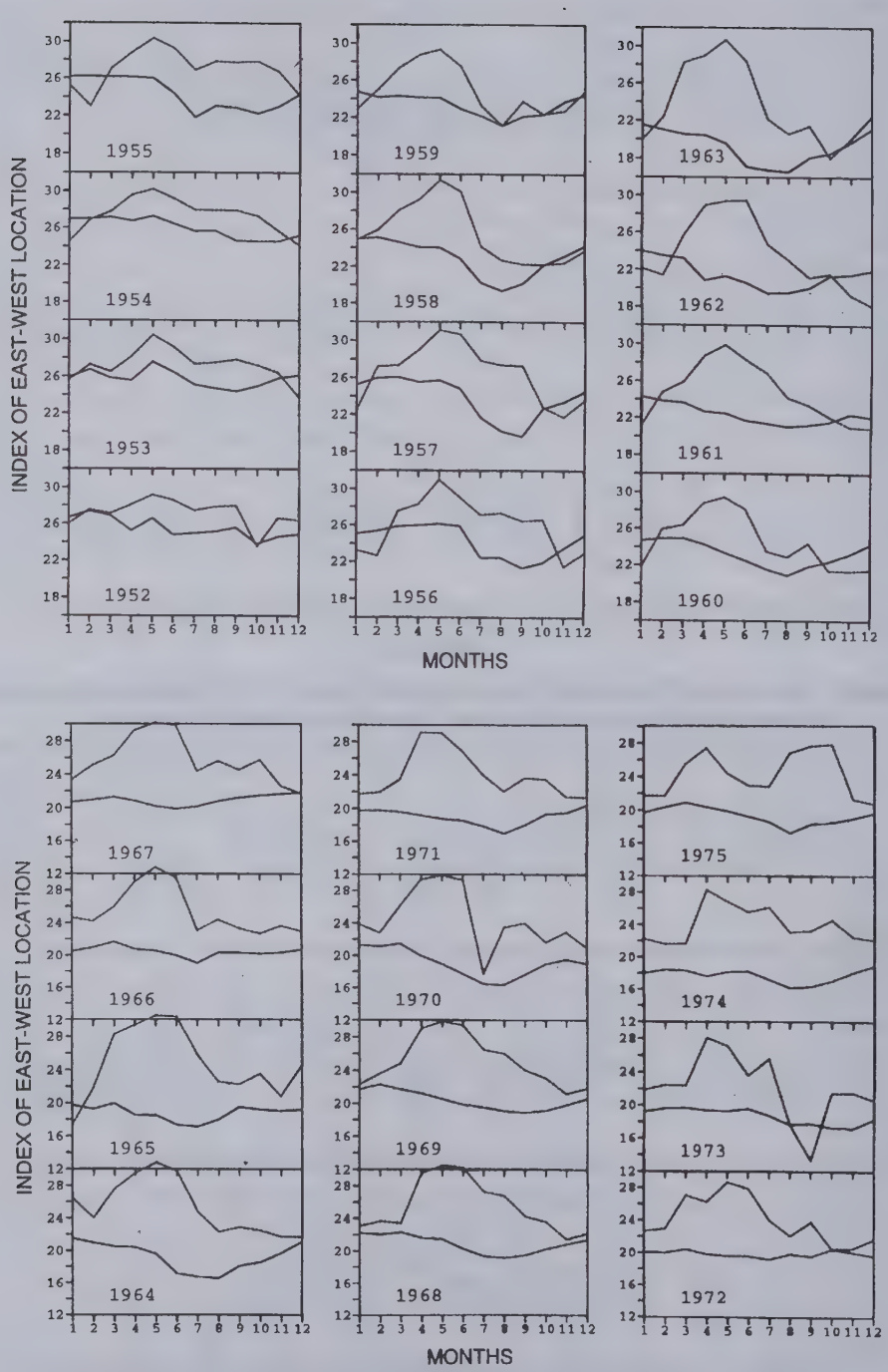

Figure 19. Annual comparisons of the Japanese longline monthly index of east-west location for the NBF catches (dotted line) from the entire Pacific Ocean to those of the effort (solid line).

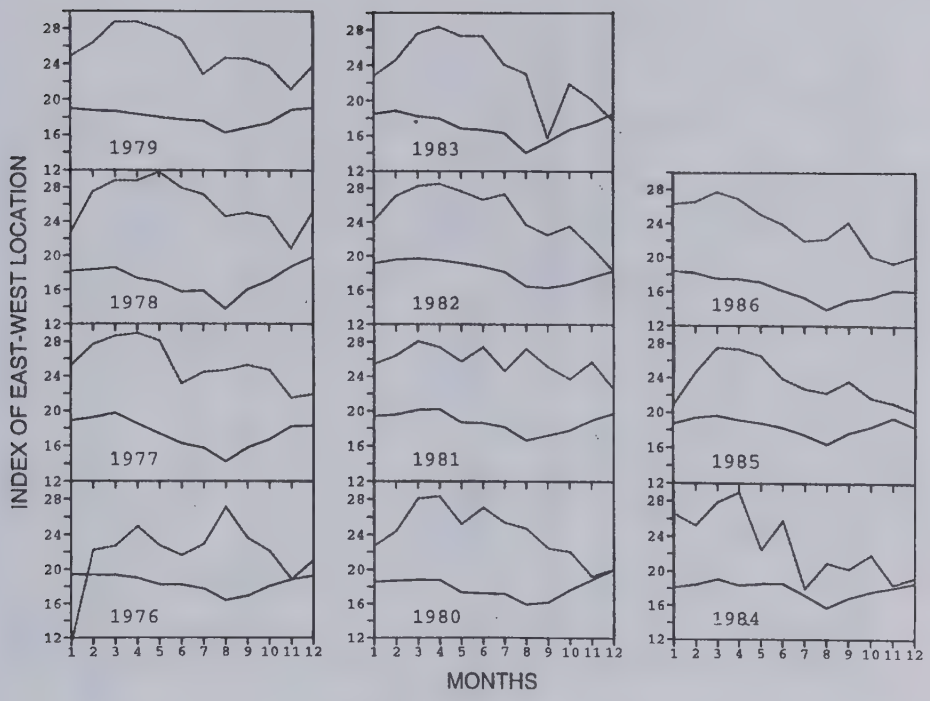

Figure 19 (continued).

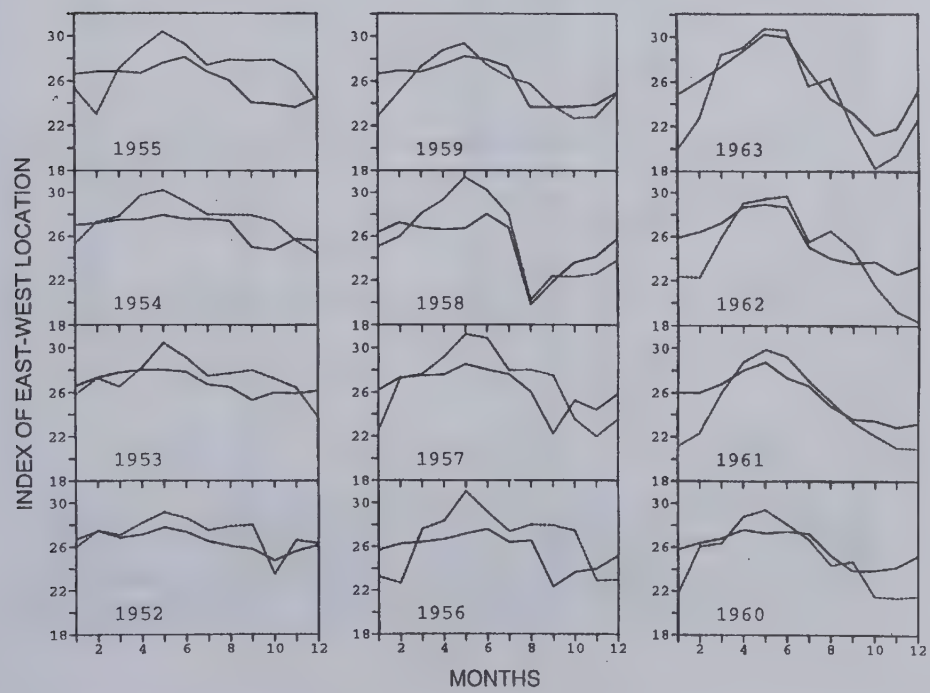

Figure 20. Annual comparisons of the Japanese longline monthly index of east-west location for the NBF catches (dotted line) from the core area to those of the effort (solid line).

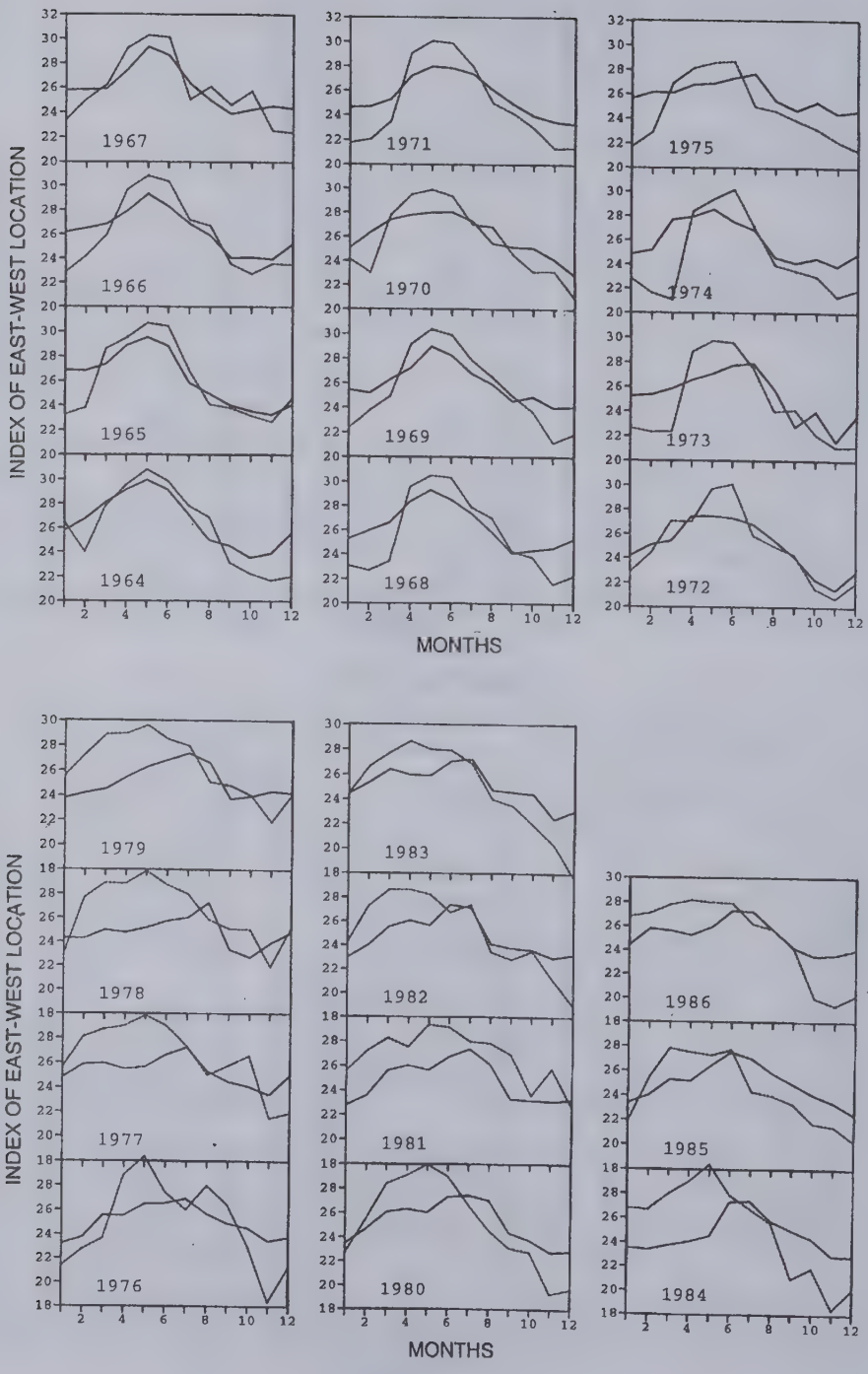

Figure 20 (continued).

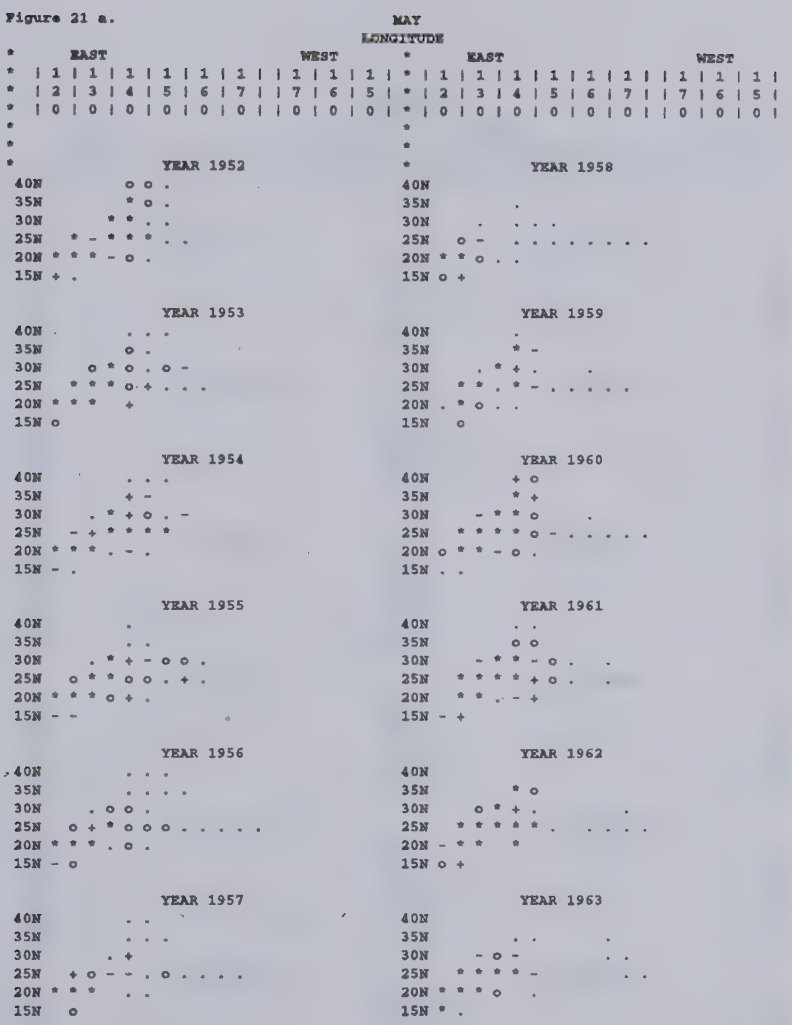

Figure 21. Annual distributions of Japanese longline catches of NBF taken within the core area during May. Catches are indicated by *, +, o, or - (with the greatest to least catches in the same order). Areas with effort, but no catch, are indicated by dots.

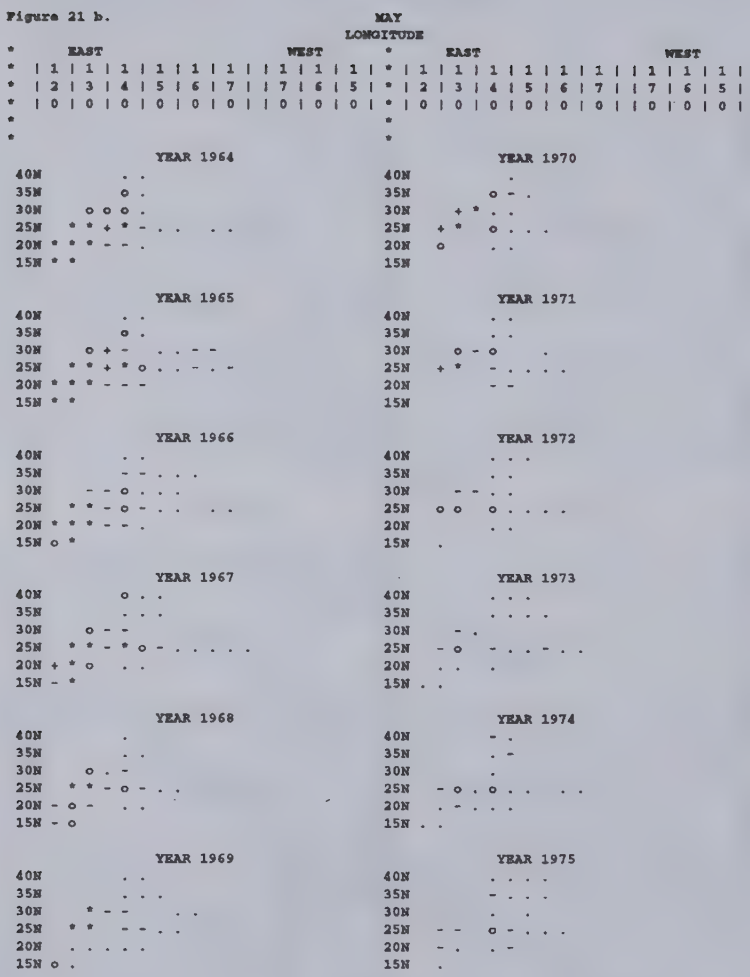

Figure 21 (continued).

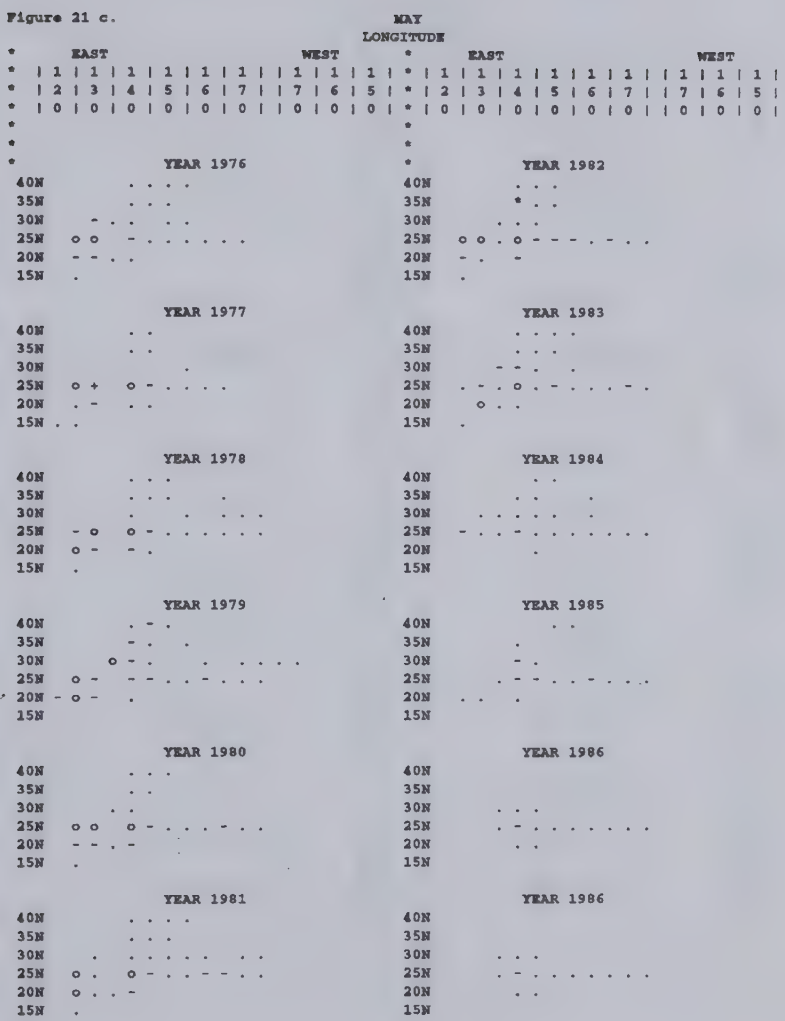

Figure 21 (continued).

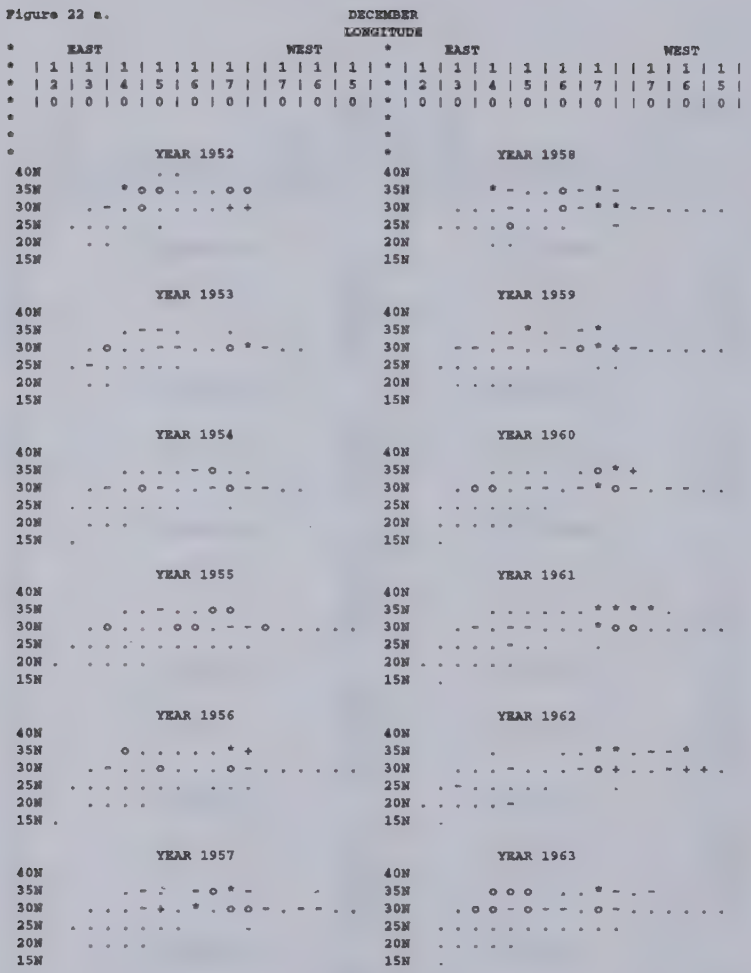

Figure 22. Annual distributions of Japanese longline catches of NBF taken within the core area during December. Catches are indicated by *, +, o, or - (with the greatest to least catches in the same order). Areas with effort, but no catch, are indicated by dots.

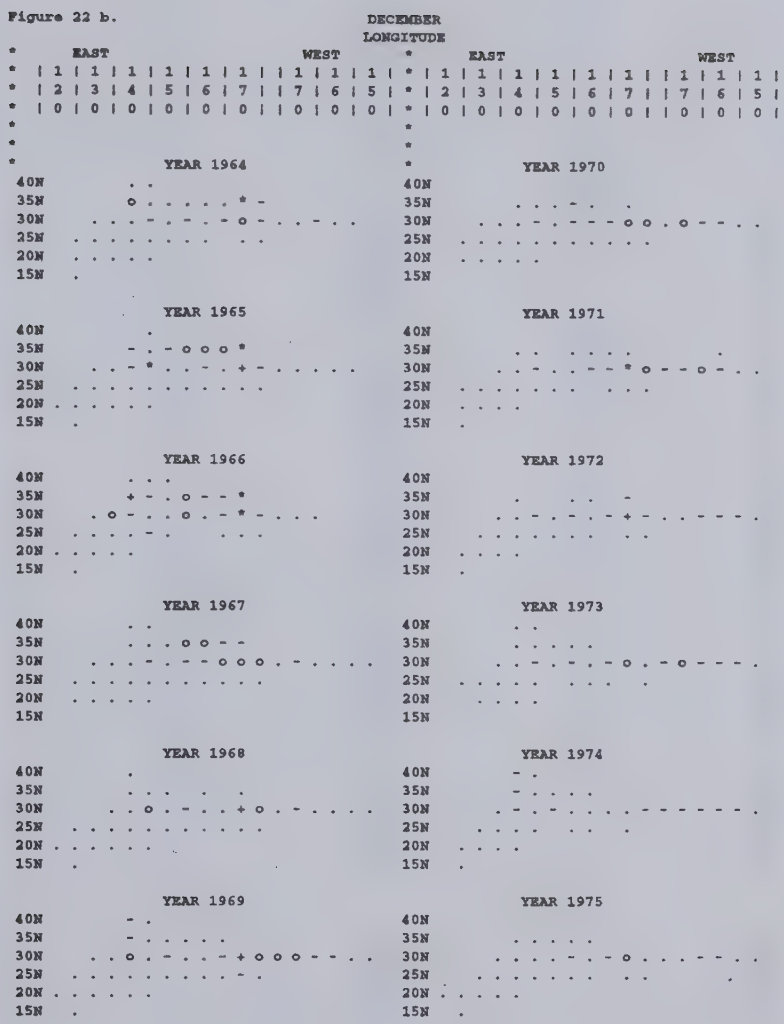

Figure 22 (continued).

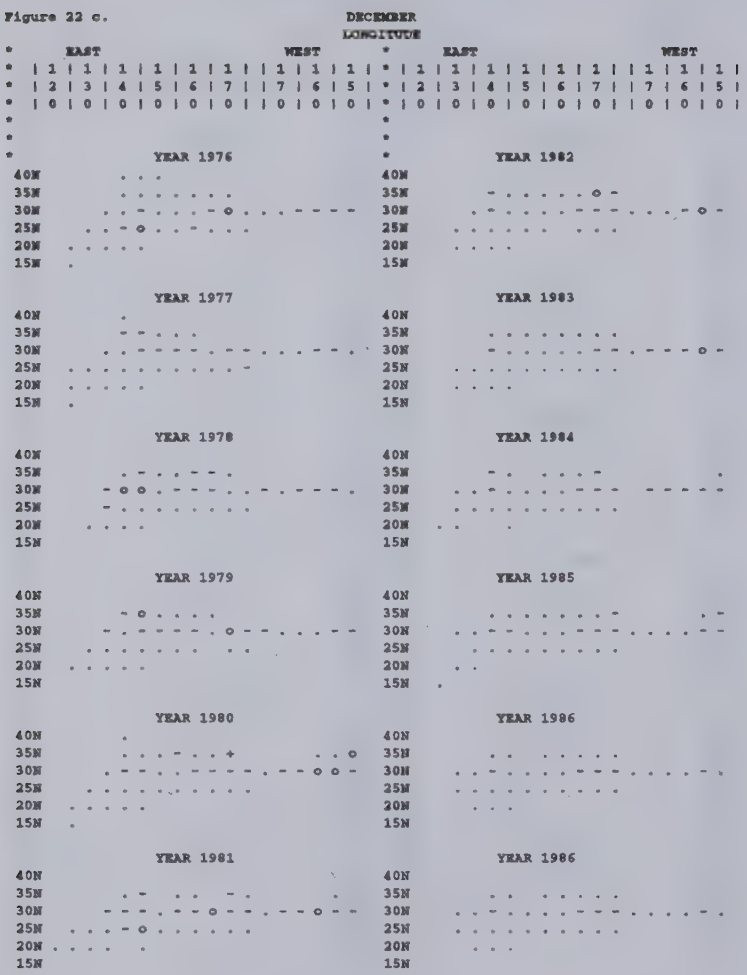

Figure 22 (continued).

Table 1. Japanese longline catches in number of northern bluefin tuna from the core area and the entire Pacific Ocean.

YEAR	CORE CATCH	ENTIRE CATCH	DIFF. ENTIRE - CORE	% DIFF. = 100*DIFF/ENTIRE
52	23853	24012	159	0.662
53	22098	22336	238	1.066
54	24125	24472	347	1.418
55	23064	23268	204	0.877
56	21293	22845	1552	6.794
57	10598	11006	408	3.707
58	6480	6684	204	3.052
59	27741	32604	4863	14.915
60	50599	51926	1327	2.556
61	50755	53833	3078	5.718
62	42970	45715	2745	6.005
63	40690	44222	3532	7.987
64	19755	20706	951	4.593
65	15342	17314	1972	11.390
66	7432	9006	1574	17.477
67	5788	6216	428	6.885
68	3568	3756	188	5.005
69	2588	2862	274	9.574
70	1628	1826	198	10.843
71	1733	2030	297	14.631
72	615	801	186	23.221
73	596	1030	434	42.136
74	583	892	309	34.641
75	342	1440	1098	76.250
76	478	1149	671	58.399
77	2105	2275	170	7.473
78	3034	3099	65	2.097
79	1958	2237	279	12.472
80	871	1216	345	28.372
81	2336	2576	240	9.317
82	2290	2437	147	6.032
83	776	882	106	12.018
84	570	748	178	23.797
85	324	412	88	21.359
86	295	395	100	25.316

Table 2. Japanese longline catches of northern bluefin tuna in numbers of fish from the Pacific Ocean.

YEAR	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEP.	OCT.	NOV.	DEC.
52	1211	277	105	613	7865	1961	2280	6224	2188	238	250	800
53	640	602	70	678	8818	5039	866	1808	2117	1061	439	198
54	760	411	554	1127	8144	2533	3759	3250	2729	840	273	92
55	351	537	408	2116	5724	1572	298	5660	3833	2123	510	136
56	235	184	437	2470	3662	1069	546	9437	3648	635	253	269
57	227	331	482	1886	2679	601	1181	2592	294	36	87	610
58	273	294	459	1023	765	461	17	101	1014	648	873	756
59	1014	1255	1183	4960	3707	3673	2021	3715	2967	1528	2845	3736
60	1061	704	3554	17384	10115	7119	873	1427	2781	1665	4532	711
61	1136	1306	3844	10297	15398	4369	3752	3433	4983	1514	1784	2017
62	1668	1355	2672	10719	16791	5206	669	1075	2057	627	1009	1867
63	884	382	2100	14799	18342	1949	335	2237	1497	589	425	683
64	581	176	1066	5603	7672	1676	227	772	1251	483	685	514
65	258	366	1369	3356	5988	2901	175	276	532	610	888	595
66	91	134	439	1432	2269	1083	593	397	866	940	367	395
67	387	226	548	871	1463	406	148	592	987	247	187	154
68	119	321	752	398	589	322	168	254	367	179	146	141
69	183	172	244	223	526	174	152	274	396	204	103	211
70	99	128	112	201	438	316	107	29	60	45	215	76
71	251	438	449	54	265	197	30	22	53	70	48	153
72	160	73	46	58	86	89	26	30	33	14	80	106
73	160	73	119	61	72	265	36	44	40	43	45	72
74	35	21	38	40	116	170	71	102	150	45	65	39
75	120	34	28	33	91	121	32	200	438	295	19	29
76	224	56	87	80	186	118	47	220	33	19	20	59
77	155	460	453	722	131	76	23	3	178	36	2	36
78	71	246	526	203	101	43	15	175	1607	35	13	64
79	123	130	241	304	98	182	63	172	720	99	48	57
80	143	51	109	179	251	82	54	50	29	25	80	163
81	373	412	677	274	81	62	26	247	133	63	130	98
82	151	293	193	162	206	424	740	87	40	37	39	65
83	99	121	219	145	46	90	16	28	16	17	33	52
84	175	133	180	10	32	17	44	54	37	16	16	34
85	84	78	74	23	9	27	28	18	13	18	20	20
86	83	70	56	15	8	66	31	18	12	10	13	13
AVG	388	339	683	2358	3507	1270	556	1286	1089	430	473	429

Table 3. Japanese longline catches of northern bluefin tuna in numbers of fish from the core area.

YEAR	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEP.	OCT.	NOV.	DEC.
52	1211	277	105	598	7839	1941	2226	6195	2183	238	250	790
53	620	602	67	669	8785	5019	832	1757	2066	1044	439	198
54	660	383	550	1075	8126	2511	3704	3238	2718	821	262	77
55	342	534	408	2075	5695	1565	261	5628	3805	2111	504	136
56	233	184	427	2398	3655	1040	517	8868	3078	569	57	267
57	225	331	431	1837	2661	574	1164	2374	285	28	80	608
58	261	292	457	1015	760	439	4	20	975	640	865	752
59	811	1225	1179	4938	3645	3651	829	533	2930	1446	2818	3736
60	1061	689	3552	17366	10092	7102	382	1015	2542	1628	4461	709
61	1131	987	3827	10201	15378	3951	3604	2655	3725	1506	1778	2012
62	1625	1148	2594	10462	16682	5092	414	599	985	585	1000	1784
63	831	346	2041	14698	18308	1629	101	140	1189	381	369	657
64	576	176	1020	5484	7624	1634	104	422	1131	423	669	492
65	170	269	1327	3209	5591	2702	52	46	400	539	444	593
66	72	134	425	1060	2151	835	120	192	808	898	362	375
67	386	222	546	833	1389	331	16	525	969	245	183	143
68	119	287	749	385	570	278	126	236	361	173	144	140
69	181	166	232	188	472	156	107	231	364	179	103	209
70	96	124	81	197	424	308	17	15	54	34	204	74
71	240	371	436	52	232	129	2	2	28	51	47	143
72	136	39	46	40	73	58	7	2	27	11	77	99
73	143	56	118	51	46	37	4	6	16	14	42	63
74	30	20	31	22	77	62	38	80	125	20	46	32
75	120	19	20	23	37	16	7	21	32	8	14	25
76	45	24	44	35	35	7	5	184	5	18	19	57
77	133	441	447	716	103	16	3	2	173	33	2	36
78	68	242	522	199	99	28	6	161	1600	33	12	64
79	115	89	238	287	70	130	1	145	687	96	44	56
80	143	35	102	146	106	58	30	0	10	12	79	150
81	362	360	655	258	44	39	3	222	110	59	128	96
82	148	286	184	159	188	413	721	20	35	37	39	60
83	81	94	214	140	41	82	7	16	8	17	28	48
84	170	117	178	10	5	9	4	10	6	16	16	29
85	73	73	71	22	7	11	3	2	6	18	19	19
86	80	67	55	12	3	27	0	4	12	9	13	13
AVG	363	306	668	2310	3458	1197	441	1016	956	398	446	421

Table 4. Japanese longline fishing effort, in thousands of hooks, in the core area.

YEAR	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEP.	OCT.	NOV.	DEC.
52	17253	13048	6278	5065	6390	1607	2354	4338	2681	4009	6686	9060
53	15815	20780	4544	2264	7190	3995	1873	1897	2074	4361	6893	12059
54	14640	19319	17421	7914	8230	5848	2850	2266	2605	3771	4925	8140
55	14468	16626	15809	10539	9133	3098	364	2127	3747	4723	8870	11818
56	13963	15107	16367	9945	8129	4486	348	739	2796	5591	9827	9018
57	14497	16868	14142	8181	6146	3110	355	1141	2413	3619	7521	13621
58	18609	14059	11809	8568	6499	3469	450	1113	3561	7555	12365	11206
59	13620	13455	14129	6412	5823	4463	3299	2967	9492	8874	12051	12183
60	17197	17919	15242	9580	8534	5906	3358	2449	9096	12078	12803	15312
61	17312	15643	16157	11075	9133	6099	6462	6121	5142	7451	11638	12250
62	13151	13348	14524	8264	7083	3216	863	1627	5149	5862	8898	8156
63	8939	9824	11629	10569	7089	1371	565	1033	4024	7620	10594	15655
64	10063	8978	9974	6696	5871	2787	1375	2917	5787	7571	5341	5140
65	8572	9381	9062	6120	5591	3337	2895	5035	7845	8808	8543	8050
66	8300	10694	10679	5917	4319	2702	3059	4973	7964	10485	9983	9918
67	14449	14944	16990	7504	4555	2259	1476	5368	9323	13524	14733	12702
68	14168	13149	11666	4626	2892	2255	2436	3017	6613	10351	13233	12156
69	15191	13415	11167	3470	2261	2162	2739	2510	6472	8278	12675	11406
70	11093	8677	6416	2756	1953	1999	2119	1958	4076	8917	9459	10928
71	10273	8111	7672	2161	1551	1834	1611	1817	5633	9212	8888	9528
72	9121	6247	3640	1903	1568	1453	1062	999	3641	5388	9010	7900
73	6447	5111	3594	2053	2084	1765	1534	1169	3650	5194	8886	8667
74	5965	3672	3206	2120	1522	1297	1208	1864	5269	6917	8598	7939
75	5397	3354	3191	2057	1911	1630	2026	1413	4700	5165	6646	10002
76	8543	6581	4748	2091	1736	1949	1656	2188	5025	8154	10570	12990
77	10970	8114	5215	2676	2406	2292	2388	1644	4737	6157	8854	10408
78	9245	7304	5579	3442	2504	2438	2383	980	3895	7308	8808	12356
79	12614	8856	5592	3616	2865	2779	2549	1207	5086	7406	9276	11719
80	7580	5597	4972	4164	2865	2252	2402	851	4712	8102	9239	13151
81	12457	7682	6931	4389	3353	2698	2269	1128	5946	7667	9178	13151
82	12887	7401	5370	3445	2790	2344	2194	3305	5501	5523	7322	9943
83	9600	7768	7062	5011	3700	3276	2532	1940	4394	6041	9239	11677
84	9488	7432	5762	3115	3177	2803	2446	3697	6040	7767	10120	11852
85	10558	8234	6901	4582	3696	3544	3251	3408	5239	6287	9468	12986
86	11311	7296	6424	5435	3952	3703	3359	2641	6719	7726	9907	10190
AVG	11822	10686	9139	5364	4529	2921	2117	2396	5173	7242	9458	10950

Table 5. Months and areas of maximum catch and effort for northern bluefin tuna caught by Japanese longliners.

YEAR	MO.	AREA	CATCH	MO.	AREA	HOOKS
1952	AUG	140 E 35 N	4571	FEB	140 E 30 N	3010309
1953	MAY	125 E 20 N	4332	FEB	140 E 30 N	5712033
1954	MAY	130 E 20 N	2777	MAR	140 E 30 N	6754806
1955	AUG	140 E 40 N	4695	FEB	140 E 30 N	4918182
1956	AUG	140 E 40 N	8785	JAN	160 E 30 N	2859595
1957	AUG	140 E 35 N	1495	MAR	140 E 30 N	2896375
1958	SEP	170 E 40 N	517	FEB	140 E 30 N	3244643
1959	APR	135 E 30 N	3707	MAR	135 E 30 N	3877797
1960	APR	135 E 30 N	14505	APR	135 E 30 N	3983831
1961	APR	135 E 30 N	6612	APR	135 E 30 N	4178016
1962	APR	135 E 25 N	5491	APR	135 E 30 N	2897219
1963	MAY	125 E 20 N	12733	MAR	135 E 30 N	4882053
1964	MAY	125 E 20 N	2970	APR	135 E 30 N	2892769
1965	MAY	125 E 20 N	2102	FEB	140 E 30 N	1996443
1966	MAY	125 E 25 N	798	OCT	155 E 35 N	4002019
1967	MAY	130 E 25 N	470	OCT	150 E 35 N	4394869
1968	MAR	170 E 30 N	571	OCT	155 E 35 N	2924598
1969	MAY	125 E 25 N	168	NOV	150 E 30 N	2486019
1970	JUNE	135 E 30 N	184	NOV	150 E 30 N	2250384
1971	MAR	170 E 30 N	310	MAR	170 E 45 S	3224520
1972	DEC	170 E 30 N	73	MAR	170 E 45 S	3273213
1973	JUNE	175 E 35 S	174	JULY	150 E 35 S	2034063
1974	JUNE	175 E 35 S	84	FEB	170 E 45 S	1914188
1975	SEP	140 E 45 N	405	MAR	170 E 45 S	2596276
1976	AUG	140 E 40 N	182	MAR	170 E 45 S	3336438
1977	APR	135 E 30 N	703	MAR	170 E 45 S	3920323
1978	SEP	155 E 40 N	1230	OCT	160 E 35 N	2084425
1979	SEP	155 E 40 N	509	MAR	170 E 45 S	3835096
1980	APR	135 E 30 N	88	MAR	170 E 45 S	4460543
1981	MAR	140 E 35 N	365	APR	170 E 45 S	3947549
1982	JULY	145 E 30 N	408	JULY	175 E 35 S	3220419
1983	MAR	140 E 30 N	167	MAY	80 W 0 N	2896969
1984	JAN	140 E 30 N	132	APR	170 E 45 S	2396459
1985	MAR	140 E 35 N	34	DEC	140 E 30 N	2526485
1986	JAN	140 E 30 N	36	DEC	140 E 30 N	2545577

Table 6. Number of 5-degree-month strata, within the core area, with Japanese longline catches of northern bluefin tuna.

YEAR	JAN.	FEB.	MAR.	APR	MAY	JUNE	JULY	AUG.	SEP.	OCT.	NOV.	DEC.
1952	9	9	5	10	17	10	5	6	4	8	11	9
1953	11	18	4	12	16	18	7	8	5	7	13	9
1954	10	17	9	15	17	20	3	4	8	15	14	9
1955	14	13	13	12	18	15	5	12	14	10	10	9
1956	10	12	9	15	14	11	6	5	6	10	5	7
1957	12	16	12	19	10	8	4	3	8	7	7	13
1958	13	16	13	14	7	8	1	5	9	11	11	15
1959	13	17	19	17	11	14	7	14	12	16	15	11
1960	18	20	24	21	19	18	10	9	14	14	11	13
1961	11	14	24	19	19	18	12	13	15	11	12	11
1962	13	21	23	21	16	16	12	9	12	16	13	15
1963	16	19	20	21	13	12	6	7	12	10	11	20
1964	15	13	13	16	16	17	13	8	9	11	7	10
1965	11	22	19	21	23	21	14	11	13	12	16	11
1966	9	14	19	20	17	12	11	12	14	12	18	14
1967	17	19	23	22	15	9	6	11	12	9	9	12
1968	7	13	15	14	12	8	4	8	10	11	11	6
1969	9	10	13	15	8	7	4	9	12	5	8	12
1970	14	12	11	6	8	10	4	3	8	6	10	10
1971	9	12	13	6	8	5	1	1	7	9	6	9
1972	10	7	4	7	5	3	2	1	3	3	5	10
1973	7	5	8	5	5	6	2	3	4	3	11	9
1974	4	7	5	6	6	3	2	7	6	5	10	10
1975	5	3	4	7	7	4	1	4	3	2	2	5
1976	7	5	8	5	6	4	3	3	2	6	8	10
1977	15	14	7	9	5	4	3	1	7	7	2	11
1978	13	9	4	7	7	4	1	3	8	4	4	14
1979	16	15	7	9	12	11	1	4	7	9	8	14
1980	11	9	10	9	8	5	3	0	5	3	12	14
1981	19	18	12	14	7	8	1	5	8	11	19	18
1982	22	16	11	11	10	10	7	5	9	11	7	12
1983	15	9	12	8	7	3	3	4	4	6	11	8
1984	11	13	8	5	2	3	3	5	4	6	11	11
1985	14	11	7	8	4	4	2	1	3	4	9	9
1986	8	11	9	6	1	4	0	2	5	3	7	5
AVG	12	13	12	12	11	10	5	6	8	8	10	11

Table 7. Number of 5-degree-month strata with Japanese longline effort within the core area.

YEAR	JAN.	FEB.	MAR.	APR	MAY	JUNE	JULY	AUG.	SEP.	OCT.	NOV.	DEC.
1952	26	27	28	25	25	16	11	13	16	19	26	27
1953	27	27	24	18	24	27	22	15	14	25	32	27
1954	29	26	27	30	25	25	20	15	22	32	33	33
1955	37	38	36	33	26	25	19	22	30	37	40	39
1956	37	35	33	30	30	24	18	16	29	41	42	39
1957	39	37	29	26	23	19	12	20	28	33	38	35
1958	35	31	27	29	22	21	13	24	24	30	32	35
1959	34	27	29	27	24	22	21	23	38	41	39	34
1960	34	36	35	30	28	33	22	21	29	39	39	37
1961	40	31	33	30	26	30	27	25	25	35	39	42
1962	37	33	41	34	23	26	22	17	27	42	47	41
1963	36	37	37	29	22	19	21	23	31	41	44	49
1964	39	34	32	26	26	25	30	21	33	43	48	44
1965	35	40	40	30	32	35	33	37	38	42	51	43
1966	43	34	32	29	30	31	27	28	37	47	42	41
1967	38	36	31	33	27	28	31	31	39	43	44	46
1968	40	35	33	26	21	23	28	26	35	35	50	45
1969	41	34	31	26	23	19	31	22	42	35	43	45
1970	42	34	26	22	19	26	31	26	35	41	40	42
1971	43	39	41	21	18	27	24	20	32	38	38	39
1972	39	37	31	26	19	18	21	20	20	26	36	41
1973	37	33	34	25	22	27	22	19	26	28	42	38
1974	35	34	26	21	20	19	21	18	23	29	38	35
1975	37	30	30	24	22	21	18	14	19	20	31	36
1976	34	36	38	25	26	26	27	26	32	43	46	42
1977	35	32	34	28	19	21	29	22	31	37	38	38
1978	33	29	29	21	27	22	21	11	32	30	35	35
1979	29	26	25	24	28	26	26	23	30	36	37	38
1980	34	27	27	24	23	20	16	16	27	35	41	42
1981	35	35	35	30	30	30	27	24	36	44	48	40
1982	35	35	31	29	24	21	19	22	28	33	35	39
1983	33	32	25	26	26	23	24	22	32	33	40	37
1984	35	34	29	24	23	25	20	25	36	32	34	36
1985	35	33	34	24	17	14	18	23	25	28	37	38
1986	33	36	33	26	14	15	21	25	31	32	36	36
AVG	36	33	32	27	24	24	23	22	29	35	39	39

INDICES OF ABUNDANCE OF NORTHERN BLUEFIN TUNA, *THUNNUS THYNNUS*, IN THE EASTERN PACIFIC OCEAN

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ABSTRACT

Catches, catches per unit of effort (CPUEs), and aerial survey data provide indices of abundance of northern bluefin tuna in the eastern Pacific Ocean. The various indices are described and compared. The habitat index, based on CPUEs of vessels fishing in spatiotemporal strata which are believed to be suitable habitat for bluefin, and the bluefin vessel index, calculated by dividing the annual catch of bluefin by the number of vessels which fish for that species, are believed to provide the most reliable indices of abundance of bluefin in the eastern Pacific Ocean.

1. INTRODUCTION

Larvae of northern bluefin tuna, *Thunnus thynnus*, in the Pacific Ocean have been found only in the vicinity of Japan, and it is assumed that spawning occurs only in that area. Some fish apparently remain their entire lives in the western Pacific Ocean (WPO). Others migrate to the eastern Pacific Ocean (EPO); these migrations begin mostly, or perhaps entirely, during their first and second years of life. The first-year migrants are exposed to the summer and fall troll fisheries for small bluefin and other species off Japan before beginning their journey to the EPO in the fall or winter. The second-year migrants are also exposed to the winter troll fishery and other fisheries which take place in the vicinity of Japan before beginning their journey to the EPO in the spring, summer or fall. The migrants, after crossing the ocean, are fished by purse seiners off California and Baja California. Eventually, the survivors return to the WPO.

The catches of northern bluefin in the EPO consist mostly of age-1 and age-2 fish. The catches of age-2 fish in the EPO exceed those of age-2 fish in the WPO in most years, whereas the opposite is the case for age-3 fish (Bayliff, 1994a). This probably indicates that the population of age-2 fish is greater in the EPO and that of age-3 fish is greater in the WPO, although it is possible that area- and/or size-related differences in fishing effort and/or vulnerability to capture are responsible for the differences in the catches.

It is obvious that there is extensive interaction between the fisheries of the WPO and the EPO. Such being the case, information on all the fisheries which take northern bluefin in the Pacific Ocean must be taken into account in any attempts to manage these fisheries. It is of fundamental importance, in stock assessment, to have indices of the abundance of the stock which is being studied. This report summarizes the various indices which have been calculated for northern bluefin in the EPO, introduces two new ones, and compares them to one another.

Ahlstrom (1960) defined abundance as "the absolute number of individuals [post-recruits] in a population" and availability as "the portion (a percentage) of the recruited population that is physically within the geographical range of the fishery during the fishing season." For northern bluefin tuna, only the fish which migrate from the WPO to the EPO are available to the surface fisheries of the EPO. Although the population of bluefin includes individuals in coastal waters of the WPO and the EPO and in offshore waters of the Pacific Ocean, henceforth in this report the word abundance should be taken to mean abundance in coastal waters of the EPO.

The catches of northern bluefin in the EPO during the 1980s and early 1990s have been much less than they were during the 1960s and 1970s. The decreased catches during recent years are believed to be due, at least partly, to lesser abundance of bluefin in the EPO (Bayliff et al., 1991; Bayliff, 1993: 88-90). Bluefin are caught mostly by vessels with carrying capacities of 400 short tons or less (size classes 1-5), and the numbers of vessels in this size range have been decreasing, so it is possible that the declining catches are due to reduced fishing effort, rather than to reduced abundance of fish. (A short ton is about 0.907 metric ton.)

2. INDICES OF ABUNDANCE

Catches, catches per unit of effort (CPUEs), and aerial survey data are used as indices of abundance of bluefin in this report. Several types of each of these are discussed below.

2.1 Catch

In general, the total catch during a year serves as an index of abundance, provided the following requirements are fulfilled:

1. the fishing effort remains constant, i.e., the numbers of vessels, the effectiveness of the gear, and the skill of the fishermen do not change from year to year;
2. the fishing effort is directed primarily at the species in question, i.e., the fishermen do not pass up opportunities to catch the species in question in order to try to catch other species;
3. the range of the species in question is the same each year;
4. the vulnerability to capture of the species in question is the same each year.

Requirements 3 and 4 are not often satisfied, but they can be ignored if a long series of data is available, the deviations from the means are not great, and there are no long-term trends in the deviations.

2.1.1 Commercial catch

Calkins (1982) stated that, since the area where bluefin are caught is subjected to intensive searching for tunas and other pelagic fish throughout the year, the "total catch may be the best indicator of bluefin abundance." That statement could be correct, or nearly so, for the 1961-80 period considered by Calkins, but it may not be true for subsequent years, due to decreased fishing effort. Commercial catch data for the EPO for 1959-91 (Bayliff, 1994b) are listed in Tables 1 and 2.

2.1.2 Recreational catch

If commercial catch data provide a realistic index of abundance, then the same may be true of recreational catch data. These vessels operate off California, off northern Baja California north of about 30°N, and in the vicinity of Guadalupe Island only, however, so they cannot provide realistic estimates of the abundance for the entire area where bluefin occur in the EPO unless the abundance off California and northern Baja California is proportional to that for the entire area. Data for the catches of bluefin aboard commercial passenger-carrying fishing vessels given by Leet et al. (1992: pages 247 and 255) are listed in Table 2. In general, bluefin are difficult to catch with recreational gear, and their vulnerability to capture varies considerably from year to year. In 1956, the year in which the greatest catches of bluefin by recreational gear were made, most of the fish were caught close to shore off Coronado, California. These fish did not form schools, so they could not be caught by purse seine vessels. During the early 1980s recreational-fishing vessels began fishing at Cortes Bank (32°20'N - 119°12'W) for the first time, which increased the catches of bluefin by these vessels (Steven J. Crooke, California Department of Fish and Game, pers. comm.).

2.2 Catch Per Unit Effort

Catch per unit of fishing effort is the most widely-used index of the abundance of fish. It is superior to catch because it is not necessary that the numbers of fishing vessels be constant from year to year. It is still necessary that the effectiveness of the gear and the skill of the fishermen be constant from year to year unless information making it possible to adjust for annual changes in these factors is available. The other requirements listed above under Catch must still be satisfied. Bluefin are caught mostly by purse seines in the EPO, but the geographic range of the purse seine fishery for tunas extends far beyond the geographic range in which bluefin occur in the EPO, so CPUE data for the EPO are unlikely to provide realistic estimates of the abundance of bluefin. The indices described below take that fact into account.

2.2.1 Calkins Index

Calkins (1982) attempted to ascertain the fishing effort directed toward bluefin during 1961-80. He adopted the following rules: (1) no effort made south of 23°N was considered to be bluefin effort; (2) no effort during the November-April period was considered to be bluefin effort; (3) no effort in 1- degree area-month strata in which no sets were made on bluefin was considered to be bluefin effort. The annual sums of the effort for 1959-91 obtained by this method are listed in Table 3 (the values in this table differ slightly from those in Calkins' Table 6 because the IATTC's files have been updated and corrected, as necessary, since 1982). Calkins calculated the CPUEs for 1961- 80 by dividing the sums of the catches of bluefin in the area-time strata in which bluefin effort was assumed to occur by the sums of the effort in those strata. The trends for this index of abundance were similar to those for the catches. When similar calculations were made for 1981-89 (Bayliff, 1991), very high CPUEs were obtained for 1985, 1986, 1987 and 1989, even though the catches were about average during 1985 and 1986 and very low during 1987 and 1989. This was apparently due to violation of Requirement 3 above, as during the years with high CPUEs the fish tended to occur in only a few area-time strata, with

high CPUEs in them. In 1989, for example, no bluefin were caught south of 30°N, and 70 percent of the catch was made during August. The Calkins indices for 1959-91 are listed in Table 2.

2.2.2 Bluefin vessel index

For this method, it is assumed that the fishing effort directed toward bluefin is proportional to the numbers of vessels which direct substantial portions of their effort to fishing for bluefin. Accordingly, each vessel of the purse seine fleet was classified each year as a "bluefin vessel" or a "non-bluefin vessel." If a vessel caught bluefin in a given year and in two or more of the four closest adjacent years (two years before and two years after the year in question), it was classified as a bluefin vessel for that year. Otherwise it was classified as a non-bluefin vessel. The criteria were relaxed for vessels which entered the EPO tuna fishery less than two years before the year in question or left the fishery less than two years after the year in question. For example, if a vessel entered the EPO tuna fishery in 1971, it was classified as a bluefin vessel for that year if it caught bluefin in 1971 and in either 1972 or 1973. This system of classification is arbitrary, and perhaps some other system would be better. However, it seems to be adequate to give some insight into the value of fleet size as a measure of the effort directed toward bluefin and total catch divided by fleet size as an index of the abundance of bluefin. Data are given in Tables 1 and 3 on the commercial catches of bluefin, the numbers of bluefin vessels in the fleet, and the numbers of purse seine vessels in the fleet. There are almost no data for Class-1 and Class-2 vessels prior to 1971 because these vessels rarely catch yellowfin or skipjack, and the IATTC staff did not begin to collect data on bluefin until 1971.

The coefficient of correlation between the catches and the numbers of bluefin vessels is 0.849 (d.f. = 27, $P<0.01$). This does not necessarily mean that the amounts of fish caught are determined mostly by the size of the bluefin fleet (or that the size of the fleet is determined mostly by the abundance of bluefin), however. For example, it can be seen that the catches during the 1961-68 period varied by a factor of 2.7 (15,897/5,889), while the number of bluefin vessels varied by a factor of only 1.2 (70/60), and that the catches during the 1981-89 period varied by a factor of 6.0 (5,084/853), while the number of bluefin vessels varied by a factor of only 1.6 (22/14). Accordingly, it appears that the fluctuations in the catches are not due primarily to fluctuations in the numbers of bluefin vessels in the fleet. There is no evidence from these data that indicates that the hypothesis of Bayliff et al. (1991) that decreased abundance of fish in the EPO is an important contributor to the reduced catches of bluefin in that area should be rejected.

Data on the numbers of purse seine vessels in the fleet are also shown in Table 1 to satisfy the curiosity of readers who might think that the comparison might be made between bluefin catches and number of vessels in the purse seine fleet. It can be seen that number of purse seine vessels increased from 1961 to 1979 and then decreased from 1979 to 1989. There appears to be no relationship between bluefin catches and total fleet size. The bluefin vessel index is the total commercial catch for each year divided by the number of bluefin vessels in the fleet during that year. Indices for 1961-89 are shown in Table 2.

2.2.3 Bluefin habitat index

Bluefin are most often caught in the EPO where the sea-surface temperatures (SSTs) are between 17° and 23°C (Bell, 1963). Accordingly, it was assumed that EPO waters north of 23°N and west of Baja California and California with SSTs in that range are suitable habitat for bluefin during the period of May through October. The decision to use only data for the area north of 23°N and only the data for May-October follows the rules of Calkins (1982). Data were assembled on logged purse seine catch and effort and SSTs in the 1-degree area-month strata fitting the above criteria. The logged catch and effort data were taken from files of the IATTC and the SST data were taken from NMFS (1960-80) and NWS (1981-91). The monthly and annual sums of the logged catches of bluefin in the EPO were divided by the monthly and annual sums of the effort in the 1-degree areas which were suitable bluefin habitat (Appendix Table 1) to get monthly and annual CPUEs of bluefin. The annual CPUEs are listed in Table 2 and the monthly and annual CPUEs in Appendix Table 1.

2.3 Aerial Survey Indices

If indices of abundance based upon visual surveys are to be valid the following requirements must be satisfied:

1. the effectiveness of the equipment and the skill of the searchers do not change from year to year;
2. the range of the species in question is the same each year;
3. the visibility of the species in question is the same each year.

Requirements 2 and 3 are not often satisfied, but they can be ignored if a long series of data is available, the deviations from the means are not great, and there are no long-term trends in the deviations. There is no need to satisfy the second requirement if the range of the surveys is the same in all years and the surveys cover the entire range of the species in all years.

Squire (1972, 1983, 1993) calculated indices of abundance for bluefin tuna from data obtained from aeroplane pilots who were searching for tunas and other pelagic fishes off Southern California and northern Baja California for fishing vessels. He calculated two indices for each year, one for "core areas" (areas in which bluefin most commonly occur) and the other for "total areas" (between 27°50'N and 38°10'N). His indices for 1962-90 are listed in Table 2.

2.4 Indices for Areas North of 28°N

The aerial indices apply only to the area north of 27°50'N, and the California-based recreational fishery takes place mostly north of 30°N. Therefore, the commercial catches, effort, and CPUEs for the area north of 28°N were calculated so that the CPUEs could be compared with the aerial indices and recreational catches. These data are listed in Tables 2 and 3 and Appendix Table 2.

3. COMPARISON OF MEASURES OF EFFORT AND INDICES OF ABUNDANCE

3.1 Measures of Effort

Five measures of effort are listed in Table 3. No adjustments have been made for differences in efficiencies of vessels of different sizes because sufficient data to perform the necessary calculations are not available. In general, for at least two reasons, larger vessels are more efficient than smaller ones. First, larger vessels are faster, so they can search for fish in greater areas per unit of time than can smaller ones. Second, larger vessels have greater carrying capacities for fish, so when they find an area where fishing is good they can usually remain there for extended periods, whereas smaller vessels often have to return to port to unload their catches while fishing is still good. On the other hand, bluefin are caught mostly by smaller vessels, which may indicate that their captains direct their effort more toward bluefin and are more skilful at catching bluefin than are the captains of larger vessels.

Four of the five measures indicate that the fishing effort for bluefin has been less during the 1980s and early 1990s than during the 1960-79 period. The exception, total number of vessels, is not a meaningful measure of effort directed toward bluefin, as most of these vessels seldom fish in the areas where bluefin occur. The decline in the measure of effort used for calculating the Calkins index is greater than those for the habitat indices. This is because the Calkins index is calculated only with effort in area-time strata where sets on bluefin were made, whereas the habitat indices are calculated with effort in area-time strata where bluefin are likely to be found (assuming that sea-surface temperature is the only factor influencing their distribution). It is the belief of the author of this report that the effort used in calculating the habitat index for the entire area is more realistic than that used in calculating the Calkins index.

3.2 Indices of Abundance

The top panel of Table 4 lists coefficients of correlation for indices of abundance involving the entire area in which bluefin are caught. All but two of these are significant at the 1-percent level, the exceptions being total catch versus the Calkins index (Test 2) and logged catch during May-October versus the Calkins index (Test 7). It was pointed out above that high values of the Calkins index were obtained for 1985, 1986, 1987 and 1989, and that this was probably due to concentration of the fish in a few small areas. When the data for 1981-91 were omitted high coefficients of correlation (Tests 3 and 8) were obtained, confirming Calkins' observation that the total catch and his index for years prior to 1981 are highly correlated. A scatter plot of the data used for Test 13 showed the point for 1989 to be an outlier, so the coefficient of correlation was recalculated without the data for 1989 (Test 14), producing a higher coefficient of correlation.

The middle panel of Table 4 lists coefficients of correlation for indices of abundance involving the area north of 28°N. Only the r values for logged catch versus habitat index (Tests 19 and 20) and Squire's (1993) core index versus his total index (Test 24) are significant. A scatter plot of the data used for Test 19 showed the point for 1986 to be an outlier, so the coefficient of correlation was recalculated without the data for 1986 (Test 20), producing a higher coefficient of correlation. It is noteworthy that the two aerial

indices are correlated significantly only to each other and that the recreational catch index is not correlated significantly with any other index.

The bottom panel of Table 4 lists coefficients of correlation for indices of abundance for the entire area in which bluefin are caught and the area north of 28°N.

Tests 27 and 28 were performed first to see if indices which were identical except for the areas included were correlated. Both of these tests produced high values of r, which indicates that the recreational catch indices and the aerial indices can be considered to be indices for the entire area of the fishery, rather than just the area north of 28°N or 30°N.

None of the original five tests involving recreational catches (Tests 30, 37, 46, 53, and 60 produced significant results. When a single outlier (1986) was removed, a significant relationship was found for the Calkins index- recreational catch comparison (Test 47).

Only one (Test 31) of the original ten tests (Tests 31, 33, 38, 40, 48, 49, 54, 55, 61, and 63) involving the aerial indices produced significant results. When single outliers (1978) were removed, the significance of one relationship increased from 5 percent to 1 percent (Test 32), three relationships which were previously insignificant became significant (Tests 34, 39, and 41), and two relationships remained insignificant (Tests 62 and 64).

Only one (Test 44) of the remaining eight original tests involving catch and/or effort data (Tests 29, 35, 42, 44, 50, 52, 56, and 58), produced insignificant results. When a single outlier (1986) was removed the relationship remained insignificant (Test 45).

For the most part, the indices of abundance derived from catch and effort data are related only to each other, as are the two indices derived from aerial observations. The recreational catch data are not related to any of the other indices. The recreational catches are probably not realistic indices of abundance, for reasons stated above, so they are not considered further. The following possibilities remain: the catch and effort data provide realistic indices of abundance; the aerial observations provide realistic indices of abundance; neither of these provides realistic indices of abundance.

The first possibility appears to be the most likely, for two reasons. First, the catches and CPUEs are highly correlated, as indicated especially by Tests 3, 4, 5 and 19. Second, most of the indices are based upon data for the entire area in which bluefin are caught, rather than only the northern part of that area. (Admittedly, however, the indices of abundance for the entire area and for its northern part are highly correlated (Tests 27 and 28).)

There are seven indices of abundance based on catch and effort data. The three based on catches can be disregarded, as these give biased results when the effort is not constant from year to year. The habitat index for the area north of 28°N can also be disregarded, as it is presumably inferior to the habitat index for the entire area in which bluefin are caught.

This leaves the Calkins index, the habitat index for the entire area in which bluefin are caught, and the bluefin vessel index. The Calkins index is biased when the range of bluefin contracts, as apparently was the case during 1985-87 and 1989-91. The habitat index may

be biased in the same way that the Calkins index is biased but, if so, it is less biased than the Calkins index. The measure of effort from which the bluefin vessel index is calculated is based upon arbitrary classification of vessels as bluefin and non-bluefin vessels, and other classification schemes would undoubtedly produce somewhat different results. There is no objective way to determine which of the two indices, the habitat index or the bluefin vessel index, is better; fortunately, however, the two are highly correlated (Test 15).

4. CONCLUDING REMARKS

The habitat indices indicate that the abundance of bluefin in the EPO has been low during the 1977-91 period, except for 1985 and 1986. The bluefin vessel indices also indicate that the abundance of bluefin was greatest during 1985 and 1986, but they indicate that it was also greater than average during 1979 and 1982. Even though both indices indicate high abundance of bluefin in 1985 and 1986, the catches were only average because the fishing effort was so low. Unless the fishing effort increases, it appears unlikely that catches greater than those of 1985 and 1986 will be taken in the future.

5. ACKNOWLEDGMENTS

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Table 1. Commercial catches (in metric tons) of bluefin in the eastern Pacific Ocean, numbers of bluefin vessels (defined in the text) in the fleet, and numbers of purse seine vessels in the fleet. The numbers 1 through 6 refer to the size classes, based on carrying capacities of the vessels in short tons (1 = 50 or less; 2 = 51-100; 3 = 101-200; 4 = 201-300; 5 = 301-400; 6 = greater than 400).

Year	Catch	Bluefin vessels							Total purse-seine vessels						
		1	2	3	4	5	6	Total	1	2	3	4	5	6	Total
1961	8,136	0	1	38	16	7	0	62	0	3	52	40	20	9	124
1962	11,268	0	0	34	22	9	0	65	0	2	46	41	29	12	130
1963	12,271	0	0	26	27	15	0	68	1	7	43	41	31	18	141
1964	9,218	0	0	27	30	13	0	70	0	1	39	45	29	20	134
1965	6,887	0	0	27	23	12	0	62	1	12	39	43	29	22	146
1966	15,897	0	0	23	27	14	0	64	0	0	34	39	32	21	126
1967	5,889	0	0	21	24	16	0	61	0	2	29	37	30	24	122
1968	5,976	0	0	21	25	12	2	60	1	11	26	34	30	37	139
1969	6,926	0	0	18	20	7	1	46	0	7	29	35	29	49	149
1970	3,966	0	0	15	17	12	3	47	0	13	24	33	27	65	162
1971	8,360	0	9	17	17	13	5	61	0	16	26	32	27	84	185
1972	13,348	0	10	16	13	12	10	61	1	22	22	34	25	102	206
1973	10,746	0	10	16	18	8	11	63	1	16	24	39	16	120	216
1974	5,617	0	14	12	15	5	7	53	0	19	27	37	15	132	230
1975	9,583	0	14	14	13	9	9	59	4	24	33	25	17	146	249
1976	10,646	0	15	11	11	11	12	60	0	24	27	25	16	158	250
1977	5,473	0	5	10	8	12	15	50	0	20	32	19	18	161	250
1978	5,396	0	9	6	6	9	16	46	0	24	37	25	20	156	262
1979	6,118	0	9	6	4	9	14	42	2	27	34	25	22	158	268
1980	2,938	0	9	4	4	7	11	35	0	17	32	25	20	164	258
1981	1,090	0	9	3	3	2	3	20	1	20	25	20	16	166	248
1982	3,150	0	10	2	2	2	4	20	1	22	16	16	13	153	221
1983	853	0	9	3	0	1	2	15	7	28	21	14	10	123	203
1984	882	0	11	1	2	0	3	17	3	27	16	9	6	105	166
1985	4,054	0	11	3	2	1	3	20	4	22	18	10	6	117	177
1986	5,084	2	14	4	0	1	1	22	5	19	19	9	5	109	166
1987	995	0	9	4	0	0	2	15	2	16	18	8	5	128	177
1988	1,423	0	10	4	0	0	0	14	2	23	17	7	6	132	187
1989	1,169	0	10	4	0	0	2	16	5	19	17	7	6	122	176

Table 2. Indices of abundance for bluefin tuna. The units are as follows: commercial catch, metric tons; recreational catch, numbers of fish; Calkins index, metric tons per day; aerial indices, metric tons per block-area flight; bluefin vessel, metric tons per year; habitat, metric tons per day.

Year	Catch				Calkins index	Aerial indices		Present study		
	Commercial			Recreational		Core	Total	Bluefin vessel index	Habitat indices	
	Jan.-Dec.	May-Oct.	May-Oct. N of 28°N						Total	N of 28°N
1959	6,914	3,091	1,060	1,330	3.67					
1960	5,422	4,466	3,152	97	3.03				2.37	3.38
1961	8,136	7,934	6,760	2,268	3.81			131	2.91	5.34
1962	11,268	9,952	7,829	2,453	3.47	5.96	3.99	173	3.45	4.98
1963	12,271	12,115	8,675	737	4.50	6.32	6.18	181	3.86	4.44
1964	9,218	7,915	4,755	693	2.66	6.32	6.18	132	2.44	4.02
1965	6,887	5,892	3,711	92	2.38	1.16	0.82	111	2.30	4.31
1966	15,897	14,544	3,605	1,998	5.86	11.82	8.58	249	5.33	3.27
1967	5,889	5,356	559	3,166	1.88	4.09	3.10	96	1.54	0.56
1968	5,976	5,005	4,218	1,231	2.52	8.57	5.47	100	2.14	3.29
1969	6,926	5,836	2,618	1,470	2.57	0.54	0.35	151	2.09	2.39
1970	3,966	3,992	662	1,833	2.25	<0.01	0.02	84	1.51	0.73
1971	8,360	7,478	2,561	749	2.87	0.79	0.38	137	2.54	2.14
1972	13,348	11,978	7,308	1,470	3.70	6.30	2.49	219	3.31	4.23
1973	10,746	9,004	5,303	5,347	3.33	15.77	14.92	171	2.75	3.63
1974	5,617	4,057	1,463	5,765	1.97	16.62	15.68	106	1.92	2.10
1975	9,583	6,579	2,316	3,348	3.87	2.36	2.30	162	3.63	4.78
1976	10,646	8,957	7,003	2,040	3.80	12.46	11.97	178	3.55	4.15
1977	5,473	4,773	2,672	1,838	2.40	7.90	6.46	110	1.75	2.13
1978	5,396	3,922	3,312	479	2.10	31.32	27.28	117	1.66	2.74
1979	6,118	4,728	2,861	1,087	2.65	11.68	11.18	146	1.44	2.83
1980	2,938	2,413	754	729	1.79	0.81	0.63	84	0.97	1.25
1981	1,090	702	629	542	1.03	0.86	0.73	54	0.46	0.93
1982	3,150	2,424	1,689	665	2.20	1.24	1.15	158	0.85	1.34
1983	853	549	534	1,912	0.75	0.05	0.18	57	0.23	0.44
1984	882	726	726	2,834	0.70	0.56	0.60	52	0.34	0.50
1985	4,054	3,358	1,891	4,980	5.99	2.10	2.33	202	3.67	3.22
1986	5,084	4,277	4,073	693	10.95	1.80	2.75	231	8.19	11.01
1987	995	772	728	1,859	4.04	0.70	0.50	66	1.54	3.00
1988	1,423	1,242	592	321	1.53	1.12	0.51	102	0.73	1.20
1989	1,169	986	986	6,519	7.05	0.93	0.44	73	1.22	3.37
1990	1,541	1,373	1,373	3,756	5.52	0.66	0.32		1.80	3.67
1991	462	415	309		5.37				1.24	2.06

Table 3. Measures of fishing effort for bluefin in the eastern Pacific Ocean.

Year	Calkins index	Bluefin vessels	Total vessels	Habitat index	Habitat north of 28°N index
1959	824.0		87		
1960	1453.0		112	1889.5	932.0
1961	2051.0	62	124	2721.5	1265.5
1962	2886.5	65	130	2890.5	1572.0
1963	2677.0	68	141	3131.5	1957.5
1964	2941.0	70	134	3240.0	1182.0
1965	2370.0	62	146	2569.5	861.0
1966	2422.5	64	126	2727.0	1102.5
1967	2812.0	61	122	3483.0	998.0
1968	1968.0	60	139	2336.0	1279.5
1969	2258.0	46	149	2801.0	1092.0
1970	1682.5	47	162	2658.5	916.0
1971	2595.5	61	185	2944.5	1196.0
1972	3220.0	61	206	3613.0	1727.5
1973	2664.5	63	216	3271.0	1461.0
1974	1974.0	53	230	2105.5	699.5
1975	1673.0	59	249	1811.0	484.5
1976	2322.0	60	250	2524.5	1685.5
1977	1948.0	50	250	2723.0	1251.0
1978	1841.0	46	262	2356.5	1211.5
1979	1771.0	42	268	3284.0	1010.0
1980	1329.5	35	258	2481.0	600.0
1981	664.5	20	248	1515.5	673.5
1982	1060.0	20	221	2845.5	1260.5
1983	651.0	15	203	2430.0	1215.0
1984	1022.0	17	166	2159.5	1463.5
1985	566.0	20	177	916.5	587.5
1986	384.0	22	166	522.0	370.0
1987	174.5	15	177	500.0	242.5
1988	755.5	14	187	1705.5	493.0
1989	140.0	16	176	808.0	292.5
1990	234.0			764.5	375.0
1991	75.0			335.0	150.5

Table 4. Correlations between different indices of availability of bluefin tuna in the eastern Pacific Ocean.

	Comparison	Coefficient of correlation	Degrees of freedom	Probability
Entire area				
1.	Total catch versus Logged catch, May-October	0.981	31	**
2.	Total catch versus Calkins index	0.151	31	n.s.
3.	same with 1981-1991 data omitted	0.867	20	**
4.	Total catch versus Vessel index	0.767	27	**
5.	Total catch versus Habitat index	0.616	30	**
6.	same with 1986 data omitted	0.872	29	**
7.	Logged catch, May-October, versus Calkins index	0.163	31	n.s.
8.	same with 1981-1991 data omitted	0.812	20	**
9.	Logged catch, May-October, versus Vessel index	0.751	27	**
10.	Logged catch, May-October, versus Habitat index	0.611	30	**
11.	same with 1986 data omitted	0.867	29	**
12.	Calkins index versus Vessel index	0.624	27	**
13.	Calkins index versus Habitat index	0.763	30	**
14.	same with 1989 data omitted	0.854	29	**
15.	Vessel index versus Habitat index	0.836	27	**
North of 28 N				
16.	Logged catch, May-October, versus Sport catch	-0.132	30	n.s.
17.	Logged catch, May-October, versus Aerial core index	0.363	27	n.s.
18.	Logged catch, May-October, versus Aerial total index	0.333	27	n.s.
19.	Logged catch, May-October, versus Habitat index	0.594	30	**
20.	same with 1986 data omitted	0.773	29	**
21.	Sport catch versus Aerial core index	0.078	27	n.s.
22.	Sport catch versus Aerial total index	0.102	27	n.s.
23.	Sport catch versus Habitat index	-0.032	29	n.s.
24.	Aerial core index versus Aerial total index	0.988	27	**
25.	Aerial core index versus Habitat index	0.090	27	n.s.
26.	Aerial total index versus Habitat index	0.106	27	n.s.

TABLE 4. (continued)

Comparison	Coefficient of correlation	Degrees of freedom	Probability
Total area versus North of 28°N			
27. Logged catch, May-October, versus Logged catch north of 28°N	0.818	31	**
28. Habitat index versus Habitat index north of 28°N	0.866	31	**
29. Total catch versus Logged catch north of 28°N	0.787	31	**
30. Total catch versus sport catch	-0.058	30	n.s.
31. Total catch versus Aerial core index	0.391	27	*
32. same with 1978 data omitted	0.586	26	**
33. Total catch versus Aerial total index	0.345	27	n.s.
34. same with 1978 data omitted	0.508	26	**
35. Total catch versus Habitat index north of 28°N	0.410	30	*
36. same with 1986 data omitted	0.631	29	**
37. Logged catch, May-October, versus Sport catch	-0.071	30	n.s.
38. Logged catch, May-October, versus Aerial core index	0.342	27	n.s.
39. same with 1978 data omitted	0.550	26	**
40. Logged catch, May-October, versus Aerial total index	0.292	27	n.s.
41. same with 1978 data omitted	0.466	26	*
42. Logged catch, May-October, versus Habitat index north of 28°N	0.396	30	*
43. same with 1986 data omitted	0.613	29	**
44. Calkins index versus Logged catch north of 28°N	0.211	31	n.s.
45. same with 1986 data omitted	0.236	30	n.s.
46. Calkins index versus Sport catch	0.245	30	n.s.
47. same with 1986 data omitted	0.470	29	**
48. Calkins index versus Aerial core index	-0.071	27	n.s.
49. Calkins index versus Aerial total index	-0.056	27	n.s.
50. Calkins index versus Habitat index north of 28°N	0.777	30	**
51. same with 1986 data omitted	0.575	29	**
52. Vessel index versus Logged catch north of 28°N	0.628	27	**
53. Vessel index versus Sport catch	-0.013	27	n.s.
54. Vessel index versus Aerial core index	0.231	26	n.s.
55. Vessel index versus Aerial total index	0.213	26	n.s.
56. Vessel index versus Habitat index north of 28°N	0.640	27	**
57. same with 1986 data omitted	0.596	26	**
58. Habitat index versus Logged catch north of 28°N	0.566	30	**
59. same with 1986 data omitted	0.696	29	**
60. Habitat index versus Sport catch	-0.012	29	n.s.
61. Habitat index versus Aerial core index	0.129	27	n.s.
62. same with 1978 data omitted	0.260	28	n.s.
63. Habitat index versus Aerial total index	0.132	27	n.s.
64. same with 1978 data omitted	0.256	26	n.s.

** significant at the 1-percent level
* significant at the 5-percent level
n.s. not significant at the 5-percent level

Appendix Table 1. Catches (C), in metric tons, effort (f), in days of fishing by purse seine vessels in "bluefin habitat," and catch per unit of effort (C/f) for bluefin tuna in the eastern Pacific Ocean.

Year	May			June			July			August			September			October			Total		
	C	f	C/f	C	f	C/f	C	f	C/f	C	f	C/f	C	f	C/f	C	f	C/f	C	f	C/f
1960	0	5.0	0.0	1612	366.0	4.4	1788	997.0	1.8	877	499.5	1.7	189	18.0	10.5	0	4.0	0.0	4466	1889.5	2.37
1961	30	104.0	0.3	1139	564.5	2.0	1078	726.0	1.5	4384	806.5	5.4	1166	434.0	2.7	138	86.5	1.6	7934	2721.5	2.91
1962	308	253.5	1.2	1887	556.0	3.4	3117	945.5	3.3	4274	954.0	4.4	367	160.5	2.3	0	21.0	0.0	9952	2890.5	3.45
1963	89	88.0	1.0	2167	356.0	6.1	1773	568.0	3.1	47101065.5		4.4	3369	921.5	3.6	7	132.5	0.1	12115	3131.5	3.86
1964	18	18.0	1.0	1461	552.5	2.6	21061215.0		1.7	35531009.5		3.5	773	430.0	1.8	5	15.0	0.3	7915	3240.0	2.44
1965	3	77.0	0.0	526	452.0	1.2	816	754.5	1.1	2282	373.5	6.1	1383	474.0	2.9	883	438.5	2.0	5892	2569.5	2.30
1966	210	136.5	1.5	4588	496.0	9.3	64121051.0		6.1	3186	782.5	4.1	149	236.5	0.6	0	24.5	0.0	14544	2727.0	5.33
1967	47	448.5	0.1	2806	636.0	4.4	21821161.0		1.9	83	425.0	0.2	222	537.0	0.5	16	275.5	0.1	5356	3483.0	1.54
1968	0	58.5	0.0	738	475.5	1.5	2042	761.5	2.7	1349	704.0	1.9	728	272.0	2.7	148	64.5	2.3	5005	2336.0	2.14
1969	505	309.0	1.6	689	489.5	1.5	2263	878.0	2.5	1744	554.5	3.2	635	352.0	1.8	0	218.0	0.0	5836	2801.0	2.09
1970	0	264.5	0.0	1461	478.5	3.1	2166	980.5	2.2	299	671.5	0.5	64	208.5	0.3	0	55.0	0.0	3992	2658.5	1.51
1971	1937	456.0	4.3	1746	304.5	5.7	1293	944.0	1.4	708	441.5	1.6	999	341.5	2.9	796	457.0	1.7	7478	2944.5	2.54
1972	341	201.0	1.7	2236	627.0	3.5	23671033.5		2.3	4864	896.5	5.4	695	566.0	1.3	1474	289.0	5.1	11978	3613.0	3.31
1973	16	107.5	0.2	1745	559.0	3.1	47351153.0		4.1	2293	961.0	2.4	215	324.0	0.6	0	166.5	0.0	9004	3271.0	2.75
1974	0	35.5	0.0	1194	413.0	2.9	1420	709.5	2.0	627	377.5	1.6	756	394.5	1.9	61	175.5	0.4	4057	2105.5	1.92
1975	53	5.0	10.5	2489	177.0	14.1	1522	630.5	2.4	364	463.0	0.8	1581	288.0	5.5	570	247.5	2.3	6579	1811.0	3.63
1976	241	64.0	3.8	1650	551.5	3.0	279	327.5	0.8	3391	500.0	6.8	3084	937.0	3.3	311	144.5	2.2	8957	2524.5	3.55
1977	1383	355.0	3.9	391	607.5	0.6	62	559.5	0.1	1956	605.0	3.3	649	512.5	1.3	332	83.5	4.0	4773	2723.0	1.75
1978	0	172.0	0.0	588	609.5	1.0	1341	601.0	2.3	1982	752.0	2.6	0	155.0	0.0	11	67.0	0.2	3922	2356.5	1.66
1979	1500	383.5	3.9	357	986.5	0.4	694	794.0	0.9	1851	660.5	2.8	214	339.5	0.6	112	120.0	0.9	4728	3284.0	1.44
1980	304	350.0	0.9	1100	825.5	1.4	239	466.0	0.5	501	282.5	1.8	269	303.5	0.9	0	253.5	0.0	2413	2481.0	0.97
1981	0	222.5	0.0	262	283.0	0.9	80	223.5	0.4	255	282.0	0.9	105	199.0	0.5	0	305.5	0.0	702	1515.5	0.46
1982	0	328.5	0.0	0	380.0	0.0	852	526.5	1.6	659	609.5	1.1	581	500.0	1.2	333	501.0	0.6	2424	2845.5	0.85
1983	0	235.0	0.0	0	646.0	0.0	250	478.5	0.5	163	606.0	0.3	98	247.5	0.4	37	217.0	0.2	549	2430.0	0.23
1984	23	256.0	0.1	81	446.5	0.2	316	910.5	0.4	125	336.5	0.4	122	60.0	2.0	59	150.0	0.4	726	2159.5	0.34
1985	27	23.0	1.2	1548	161.0	9.6	322	292.5	1.1	762	170.0	4.4	130	145.0	0.9	570	125.0	4.5	3358	916.5	3.67
1986	15	13.0	1.1	307	49.5	6.2	1551	181.0	8.5	1560	130.5	12.0	363	57.0	6.4	482	91.0	5.3	4277	522.0	8.19
1987	0	13.5	0.0	33	38.0	0.8	261	132.5	2.0	245	154.5	1.5	188	89.5	2.1	45	72.0	0.6	772	500.0	1.54
1988	0	5.0	0.0	215	167.0	1.3	852	660.0	1.3	99	504.0	0.2	16	172.0	0.1	60	197.5	0.3	1242	1705.5	0.73
1989	0	15.0	0.0	0	83.0	0.0	6	127.0	0.1	732	221.0	3.4	212	254.5	0.8	35	107.5	0.4	986	808.0	1.22
1990	0	100.5	0.0	0	202.5	0.0	470	141.0	3.4	288	178.0	1.6	536	79.0	6.8	79	63.5	1.3	1373	764.5	1.80
1991	0	1.0	0.0	98	6.0	16.3	16	55.0	0.3	301	160.5	1.9	0	75.5	0.0	0	37.0	0.0	415	335.0	1.24

Appendix Table 2. Catches (C), in metric tons, effort (f), in days of fishing by purse seine vessels in "bluefin habitat" north of 28°N, and catch per unit of effort (C/f) for bluefin tuna in the eastern Pacific Ocean.

Year	May			June			July			August			September			October			Total		
	C	f	C/f	C	f	C/f	C	f	C/f	C	f	C/f	C	f	C/f	C	f	C/f	C	f	C/f
1960	0	0.0	0.0	548	118.0	4.6	1539	353.0	4.4	877	440.0	2.0	189	18.0	10.5	0	3.0	0.0	3152	932.0	3.38
1961	30	0.0	-	153	33.0	4.6	889	232.5	3.8	4384	707.0	6.2	1166	274.5	4.3	138	18.5	7.4	6760	1265.5	5.34
1962	26	5.0	5.3	204	0.0	-	2958	667.0	4.4	4274	771.0	5.5	367	124.0	3.0	0	5.0	0.0	7829	1572.0	4.98
1963	89	19.0	4.7	24	4.0	6.2	535	50.5	10.6	4650	870.5	5.4	3369	906.0	3.7	7	107.5	0.1	8675	1957.5	4.44
1964	18	0.0	-	54	1.0	54.4	440	111.0	4.0	3553	887.5	4.0	686	174.5	3.9	5	8.0	0.5	4755	1182.0	4.02
1965	3	0.0	-	0	6.0	0.0	3	22.5	0.1	1523	291.5	5.3	1377	369.0	3.7	806	172.0	4.7	3711	861.0	4.31
1966	7	1.0	7.3	0	11.5	0.0	284	100.0	2.7	3186	764.5	4.2	101	201.0	0.5	0	24.5	0.0	3605	1102.5	3.27
1967	0	0.0	0.0	91	12.0	7.5	211	180.0	1.2	18	144.0	0.1	222	537.0	0.5	16	125.0	0.1	559	998.0	0.56
1968	0	0.0	0.0	3	12.0	0.2	1989	383.5	5.2	1349	601.5	2.3	728	245.5	3.0	148	37.0	4.0	4218	1279.5	3.29
1969	36	0.0	-	46	41.5	1.2	171	294.0	0.5	1731	532.5	3.3	634	188.0	3.4	0	36.0	0.0	2618	1092.0	2.39
1970	0	0.0	0.0	0	21.5	0.0	298	286.5	1.0	299	507.5	0.6	64	89.5	0.7	0	11.0	0.0	662	916.0	0.73
1971	2	9.0	0.2	0	0.0	0.0	57	84.0	0.7	708	402.0	1.7	999	341.5	2.9	796	359.5	2.2	2561	1196.0	2.14
1972	0	0.0	0.0	8	12.0	0.7	503	121.0	4.2	4657	774.5	6.0	670	531.0	1.3	1470	289.0	5.1	7308	1727.5	4.23
1973	16	1.0	16.3	0	7.0	0.0	2844	526.5	5.4	2228	746.5	3.0	215	157.0	1.4	0	23.0	0.0	5303	1461.0	3.63
1974	0	0.0	0.0	0	6.0	0.0	232	105.5	2.2	507	265.0	1.9	701	295.0	2.4	23	28.0	0.8	1463	699.5	2.10
1975	0	0.0	0.0	6	0.0	-	275	98.5	2.8	306	107.0	2.8	1273	177.0	7.2	456	102.0	4.4	2316	484.5	4.78
1976	0	0.0	0.0	4	18.5	0.2	279	154.5	1.8	3336	438.5	7.6	3079	932.0	3.3	306	142.0	2.2	7003	1685.5	4.15
1977	0	0.0	0.0	14	53.0	0.3	62	170.5	0.4	1948	551.0	3.5	649	423.5	1.5	0	53.0	0.0	2672	1251.0	2.13
1978	0	2.0	0.0	91	24.0	3.8	1265	372.5	3.4	1946	661.0	2.9	0	134.0	0.0	11	18.0	0.6	3312	1211.5	2.74
1979	0	0.0	0.0	0	10.0	0.0	685	145.5	4.7	1851	479.5	3.9	214	304.0	0.7	112	71.0	1.5	2861	1010.0	2.83
1980	0	3.5	0.0	0	12.0	0.0	14	35.0	0.4	471	226.0	2.1	269	275.5	1.0	0	48.0	0.0	754	600.0	1.25
1981	0	5.0	0.0	262	50.0	5.3	70	163.0	0.5	210	254.5	0.8	87	178.5	0.5	0	22.5	0.0	629	673.5	0.93
1982	0	0.0	0.0	0	8.0	0.0	117	64.5	1.8	659	403.0	1.6	581	453.0	1.3	333	332.0	1.0	1689	1260.5	1.34
1983	0	4.0	0.0	0	5.0	0.0	250	196.5	1.3	149	545.0	0.3	98	247.5	0.4	37	217.0	0.2	534	1215.0	0.44
1984	23	4.0	5.6	81	155.5	0.5	316	828.5	0.4	125	304.0	0.5	122	60.0	2.0	59	111.5	0.5	726	1463.5	0.50
1985	0	0.0	0.0	268	18.5	14.4	206	144.0	1.5	718	161.0	4.4	130	141.0	0.9	570	123.0	4.6	1891	587.5	3.22
1986	15	1.0	14.5	216	16.5	13.1	1438	138.5	10.3	1560	121.0	12.9	363	52.0	7.0	482	41.0	11.8	4073	370.0	11.01
1987	0	2.0	0.0	8	5.0	1.6	241	46.0	5.3	245	72.0	3.4	188	57.5	3.3	45	60.0	0.7	728	242.5	3.00
1988	0	1.0	0.0	1	12.0	0.7	416	185.5	2.3	99	184.0	0.5	16	55.5	0.3	60	55.0	1.1	592	493.0	1.20
1989	0	0.0	0.0	0	3.0	0.0	6	7.5	0.8	732	117.0	6.3	212	145.5	1.5	35	19.5	1.8	986	292.5	3.37
1990	0	2.5	0.0	0	3.0	0.0	470	123.0	3.8	288	105.0	2.7	536	79.0	6.8	79	62.5	1.3	1373	375.0	3.67
1991	0	0.0	0.0	0	0.0	0.0	10	10.0	1.0	299	80.0	3.7	0	55.5	0.0	0	5.0	0.0	309	150.5	2.06

INTERACTIONS OF ATLANTIC BLUEFIN TUNA FISHERIES

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ABSTRACT

Examples of interactions among Atlantic bluefin tuna fisheries are reviewed. Analyses of the impact of reductions in historical catches of small bluefin tuna in the western Atlantic were conducted under a hypothesis of a western Atlantic resource negligibly affected by mixing with bluefin from the eastern component of the resource. The analyses indicated that abundances of larger bluefin and, presumably, catch rates in associated fisheries for that size range would have increased. Analyses conducted under one set of hypotheses about mixing behaviour and mixing rates between eastern (including the Mediterranean Sea) and western components of the resource investigated the impacts of alternative levels of fishing in each area on projected abundances. Different catch levels of the more abundant eastern component were shown to impact the western component, while different catch levels for the western area showed no impact on the eastern component.

INTERACTIONS BETWEEN SURFACE AND LONGLINE FISHERIES FOR SOUTHERN BLUEFIN TUNA BASED ON RECENT TAGGING RESULTS: THE IMPLICATIONS OF REPORTING RATES

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ABSTRACT

Little direct evidence exist for large interactions between surface and longline fisheries for tunas. Previous tagging experiments suggest low rates of mixing and interaction among the fish caught in these two types of fisheries. Results are presented from recent and on-going tagging experiments on southern bluefin tuna (SBT) and compared with tagging results from the 1980s. In contrast to results obtained in the 1980s, the most recent tagging experiments suggests rapid and significant interchange of fish between the two fisheries as evidenced both by the relative recovery rates from the two types of gear and by the spatial and temporal distributions of the recoveries. Results are also presented for a limited number of SBT tagged and released from longline vessels indicating that substantial mixing occurs not only from surface fisheries into the longline fisheries but from longline fisheries into surface fisheries. The results do not support any previous speculations that the surface and sub-surface fish may constitute biologically or behavioural different components of the stock.

The difference in the results for this most recent tagging program and previous ones appears to be due to increased reporting rates from longline vessels as the result of very substantial tag recovery efforts which have included extensive direct contact between vessels and scientists, observers or tag liaison personnel. Thus, over 85% of the tag recoveries from Japanese longliners are the result of such direct contacts prior to vessels returning to Japan. However, comparison of tag recovery rates from longline vessels with and without observers in the same area and season suggests that recovery rates are still below 100%. Overall, the results emphasize the critical need for well developed and extensive tag recovery programs if results from large scale tagging programs are to be used to investigate and measure interactions between fisheries. Low return rates from longline vessels should not be used as an indication of lack of interaction or lack of potential for interactions between surface and longline fisheries without a careful assessment on reporting rates.

1. INTRODUCTION

The major commercial fisheries for tuna can be divided into two basic types based on the depth at which fish are captured--those that catch fish near the surface (i.e., by purse seine, pole and line, and troll gear) and those that concentrate on sub-surface fish, generally below 75 m (i.e., longline fisheries). Surface fisheries generally focus on schooling aggregations of juvenile and sub-adult fish while longline fisheries generally

harvest larger and adult fish. However, fish over a wide size range can and are captured by both surface and longline gear. The catch from surface fisheries has been generally targeted for high volume markets (e.g., canning) and a single successful operation usually captures large quantities of fish (tens to hundreds of tonnes). In contrast, longline fisheries tend to target the lower volume but high valued sashimi market with a primary emphasis on fish quality. Successful operations generally catch small numbers of fish (a few to a few hundred fish per day).

Given the difference in the size range and market strategies between surface and longline fisheries, intense competition and interactions would be expected in situations in which there were moderate to high exploitation rates by the surface fisheries based on simple yield per recruit considerations (e.g., Suzuki, 1986; Fonteneau, 1987; Hampton, 1989; Miyabe, 1994). Moderate to high exploitation rates by longline fisheries could also be expected to lead to negative interactions via recruitment over-fishing, particularly in cases where there were also significant surface fisheries (e.g., Polacheck, 1994).

Somewhat surprisingly, there is little direct evidence for large interactions between surface and longline fisheries. Large scale tagging programs have been conducted for many of the main tuna stocks of various species in different regions (see Bayliff, 1993). For practical reasons (e.g., the number of fish that can be tagged per day, access to longline vessels, etc.), these tagging programs have almost exclusively tagged and released fish captured in surface operations. While large numbers of tagged fish have been recaptured by surface fisheries, the subsequent reported number of recaptures by longline vessels from these various programs has been small, both in absolute numbers and relative to the tag recapture rates from surface fisheries. Where quantitative analyses have been performed based on the tag return results, they suggest low rates of mixing and interaction among the fish caught in surface and longline fisheries (Lenarz and Zweifel, 1979; Fonteneau, 1988; Kleiber and Baker, 1987; Hampton, 1989; SPC, 1994). This has lead to speculation that the surface and sub-surface fish may constitute biologically different components of the stock at least over those size ranges caught by both surface and longline gears (Fonteneau, 1987; Polacheck, 1988; Hampton, 1994; SPC, 1994).

A major collaborative tagging program for southern bluefin tuna (SBT) involving the Commonwealth Scientific and Industrial Research Organization of Australia (CSIRO) and the National Research Institute of Far Seas Fisheries of Japan (NRIFSF) was begun in 1990. This program is on-going with from 6,900 to 16,500 tags released in each fishing season since 1990/91. Plans are in place to continue tagging for several more seasons. The results to date suggest a substantially different picture of the interaction between SBT caught in surface and longline fisheries than the general picture described above that has emerged from other tagging studies, both on SBT and other tuna species. The purpose of the present paper is to present some preliminary results documenting the interactions that are being observed and to compare these results with those from an earlier tagging experiment conducted in the 1980s. The likely reason for the difference in the results from this most recent experiment are also discussed. Overall, the results indicate the need for caution when inferring interactions or potential interactions (or lack thereof) between surface and longline tuna fisheries based on the results from past tagging experiments.

2. MATERIALS AND METHODS

2.1 Description of Tagging Programs

The basic tagging procedure used in the 1983/84 and 1990s tagging experiments were similar (see Williams, 1982, 1992; Hearn et al., 1991). Most fish tagged were caught by pole and line with a barbless hook while small numbers were caught by troll lines. In addition, a pilot experiment involving the release of longline caught fish is being conducted in the 1990s (Williams, 1993) and results from this pilot experiment are considered separately below.

After a fish had been hooked, it was hauled aboard the vessel and placed in a vinyl cradle[1]. The fish were than doubled tagged by experienced operators with 12 cm dart tags inserted about 4 cm to the rear of the second dorsal fin on either side of the fish. During the 1980s a small percentage of the tagged fish were injected with oxytetracycline marking the calcareous tissue to assist in the validation of ageing from hard parts. In the 1990s approximately 50% of the tagged released fish were injected with a small dose of strontium chloride for the same purpose. Normally tags are yellow, except that orange tags are attached to injected fish. Recovery rates of tags from injected and non-injected fish have been similar (Gunn et al., 1994), but there is a need to increase the recovery rate of hard parts from orange tagged fish. Fork lengths were measured and tagged fish were returned to the water within 30 seconds of being captured.

Tagging operations in both the 1980s and 1990s were concentrated in the nearshore, surface water fisheries bordering the central and western southern coast of Australia (i.e., the states of Western and South Australia). The South Australia tagging took place in the Great Australian Bight or in the adjacent shelf waters generally between 130° and 135°E longitudes while releases in Western Australia occurred in the Albany (i.e., between 116° and 119°E longitude) and Esperance areas (between 119° and 125°E). Fish are generally smaller/younger in the Western Australia area reflecting a general west to east migration/movement of juvenile fish along the southern coast of Australia (Figure 1)[2].

The total number of tags released in the 1983/84 experiment was 10,188 and 42,832 tags have been released to date in the on-going 1990s experiment in Western and South Australia (See Table 1 for more detail). Fish tagged in 1983/84 were primarily from the 1982 and 1983 cohorts while most fish tagged to date from the 1990s program are from the 1988 to 1992 cohorts (Table 2). The method used to assign tagged fish to cohorts is described below.

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[1] In case of the pilot longline experiment and the tagging of a small number of troll-caught fish off eastern Tasmania in the 1990s, foam mattress were used instead of vinyl tagging cradles.

[2] In the results below, it will be noted there are almost no recoveries from Western Australia in the 1990s. This lack of recoveries reflects the almost total cessation of commercial surface fishery operations for SBT in this area as the result of the introduction of restrictive quotas and a change in markets toward high valued sashimi products. The small size of fish that were previously caught in the Western Australian surface fishery are not suitable for the sashimi market. However, in recent years there has been some SBT caught in the general Western Australia areas by Australian/Japanese joint venture longline vessels.

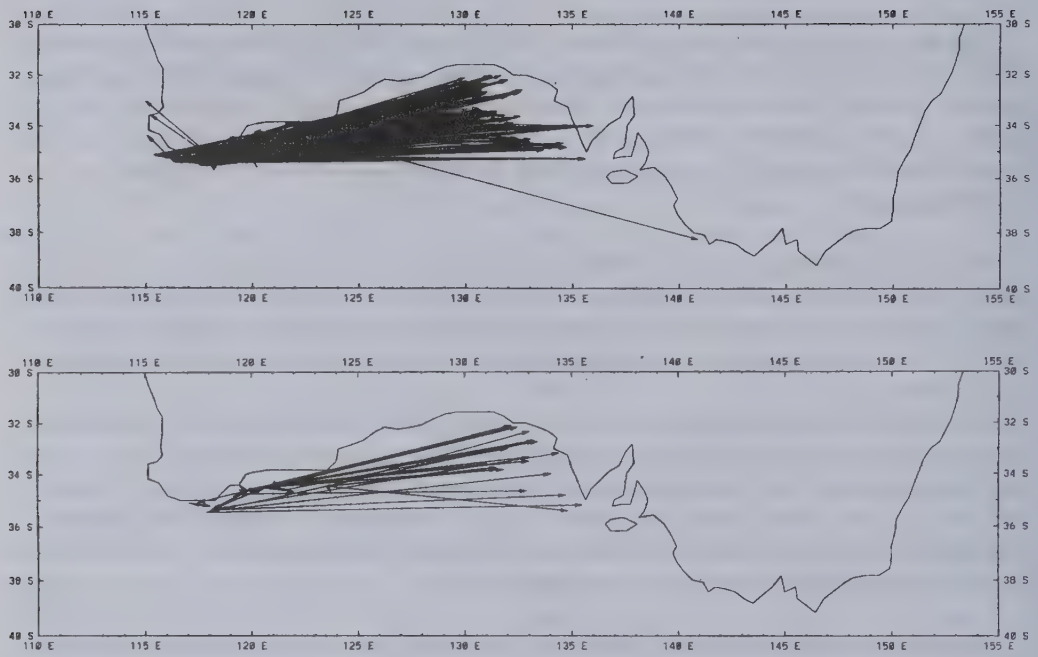

Figure 1. Release and recapture locations of fish tagged in Western Australia by surface gears with times of liberty less then 1 year; a (top) 1983/84 releases, b (bottom) 1990s releases.

In addition to these releases off the southern coast of Australia, a small number of SBT (86) were tagged and released in May and June of 1991 from nearshore waters off Eagle Hawk Neck in eastern Tasmania from troll-caught fish. In 1993, an additional 34 fish were tagged from trolling operations around Eagle Hawk Neck. In 1992, a trial release of 88 small fish was conducted from a Japanese longline vessel fishing in nearshore waters off eastern Tasmania and, in a continuation of these trials, an additional 364 were released in 1993 (Williams, 1993).

2.2 Description of Recovery Activity

Historically, the major fisheries for SBT have been the Australian surface fishery and the Japanese longline fishery with smaller scale New Zealand surface and longline fisheries (see Caton, 1994, for more detail). Recently, there has been increased longline catches of SBT by Taiwan and Indonesia plus small catches reported by Korea. The Australian surface fishery catches predominantly juvenile fish using primarily purse seine and pole-and-line gear. While historically, there were fisheries off New South Wales, South Australia and Western Australia, the juvenile fishery off NSW collapsed in the late 1970s/early 1980s due to lack of fish and the Western Australian fishery decline rapidly after 1985 with the introduction of catch quotas. In the 1990s, over 90% of the surface Australian catch has come from South Australia. While the Japanese longline fishery began

on the spawning grounds south of Indonesia in the 1950s, by the late 1960s the fishery had shifted away from the spawning grounds and expanded to areas encompassing the southern feeding grounds (i.e., areas 3-9, Figure 2). The longline fishery catches both juvenile and adult fish. Effort in the fishery increased through the early 1980s but has decreased in recent years as the result of the catch quotas.

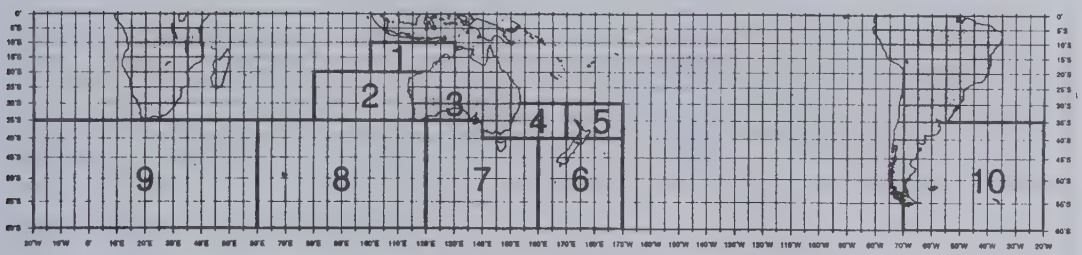

Figure 2. Large scale statistical areas used for reporting Japanese longline SBT catch and effort data (Note that the definition of areas 6 and 7 was revised in 1994).

2.2.1 Australian Fisheries

Tag recovery from Australian fishermen in both the 1983/84 and 1990s experiment depended to a large extent on field officers who had close and frequent contact with fishermen and processing workers. For each tag returned, the finder was given a reward (monetary in the 1983/84 and a choice of monetary, t-shirt, cap or coffee mug in the 1990s) and a letter or certificate with the corresponding fish release and recapture information. For both sets of experiments, it was possible to achieve a high level of awareness of the programs because there were relatively few vessels fishing for SBT and few companies processing them (the number of vessels in the 1990s were fewer than in the 1980 period) and there was an active liaison officer who had extensive contact and interactions with the industry.

For the 1983/84 experiments, meetings were held with fishermen and articles published in trade magazines explaining the need and purpose of the programs (Majkowski and Murphy, 1983; Williams, 1983). In addition, rewards posters, pre-paid postage envelopes and recapture forms were sent to all quota holders and processing establishments. In addition, a lottery in which all tag returners during the 1986/87 season were entered was well advertised and winners drawn in 1987. The total monetary rewards could be substantial for individual tag returners in the 1980s because of the high recovery rates (see below).

Table 1. Number of tags released by area, month and year.

Year	Month	Area	Number of releases
1983	January-March	W. Australia	4591
	August-October	W. Australia	2365
1984	January-February	S. Australia	3232
1990/91	November-January	W. Australia	3307
1991	January-February	S. Australia	4352
	May	Tasmania (trolling)	86
1991/92	December-January	W. Australia	3052
1992	January-February	S. Australia	4998
	June	Tasmania (longline)	88
1992/93	November-March	W. Australia	4941
1993	January	S. Australia	5873
	May-June	Tasmania (longline)	364
	April-June	Tasmania (trolling)	34
1994	January-March	W. Australia	8679
	January-February	S. Australia	7629
	June	Tasmania (longline)	196

Table 2: Number of tags released by estimated cohort and release year.

	Release Year[1]					
Cohort	1983	1984	1991	1992	1993	1994
1980	3	8				
1981	322	40				
1982	5667	692				
1983	945	2478				
.....						
1988			384			
1989			3405	618	5	2
1990			3956	5458	2367	94
1991				2061	3824	2852
1992				1	5016	4261
1993						9281
no length	19	14				14
TOTAL	6,956	3,232	7,745	8,138	11,212	16,504

1) From November of the previous year through October of the current year

Similar activities have been conducted in the 1990s but even more intensively. The further contraction/reduction of the Australian surface fishery in the 1990s has meant that almost all surface caught fish are landed in Port Lincoln, South Australia and a very high proportion of the vessels are met by a liaison officer at the time of landing. A number of

promotional trips have been conducted by liaison officers along the east coast of Australia and in Tasmania targeting the developing Australian domestic longline fishery. Repeated personal contact has occurred with all of the processors and a high percentage of the fishermen. In addition to articles in trade magazines (Whitelaw and Hearn, 1991; Whitelaw, 1992a, 1992b; Whitelaw et al., 1992; Anon., 1993; Whitelaw and Mawson, 1993; Hearn et al., 1994), the tagging program has sought and received substantial publicity by both local and national media (newspaper, TV and radio). Annual lotteries have been held for tag returners and the turn around time for feedback to tag returners in terms of payment of rewards and tag certificates has been short. One complication in the 1990s is that an increasing fraction of the surface catch is going directly into farming operations (approximately 70% in 1994) without fish ever having been removed from the water. This has meant that tags can only be detected when fish are harvested from the farms. This usually occurs over a protracted time period when there is less direct liaison contact (although in a few instances, liaison personal have been able to observe the harvesting of entire farms).

2.2.2 Japanese longline fisheries

In the 1983/84 experiment, CSIRO scientists depended primarily on their contacts with Japanese SBT research scientists through the SBT assessment process for promoting and recovery of tags, although the cooperation was also sought from the Federation of Japan Tuna Fisheries Cooperative Associations at various fora. Rewards and tag certificates were sent to tag finders in Japan, but this often involved a long delay because of the distance and logistic problems. Furthermore, the reward often went to the vessel owner or fishing master and not the actual tag finder. In 1987, a poster promoting the program was produced in Japanese for distribution to vessels in Japan. There is little information available on the extent of direct contact that was made with vessels and crews to publicize the program or on the distribution of promotional materials. After 1987, shipping agents and inspectors were asked to inquire for tags when Japanese vessels visited the Australian ports of Hobart and Fremantle. When tags were returned in Hobart, rewards were generally immediately given to tag finders by CSIRO scientists. In addition, Australian observers aboard Japanese vessels fishing with in the AFZ were aware of the program, but the actual observer coverage was very low during the 1984 to 1987 period (no more then a total of two weeks of coverage on a single vessel in any given year).

In the 1990s, a much more extensive effort has been developed to promote the tagging program and encourage the reporting of tags from recaptured fish from Japanese longliners. This has been made possible, in part, by the collaborative framework under which the research is being done and by the closer personal links that have developed between Australian and Japanese scientists and industries. It has also been made possible by the appointment within CSIRO of a full time industry/science liaison officer for tuna fisheries. A major components of this job includes responsibilities for tag promotion and recovery activities. The more extensive effort to promote the current tagging program has included:

1) production of posters and informational material in Japanese;

2) personal port visits to nearly 100% of all Japanese longline vessels during port calls in Australia. Since most vessels are required to undergo both a pre- and post- vessel inspection when fishing within Australian waters, this means that most vessels are

visited twice during any season. Visits in Hobart and Fremantle are conducted by CSIRO personal while visits in Sydney and Brisbane are conducted by contracted Japanese speaking liaison officers (Table 3). We have avoided using marine police or inspectors for this role, although they have been informed about the program and a small number of tags have been returned directly to them;

Table 3. Number of vessel visitation to Japanese longline vessels by CSIRO scientist and contracted Japanese speaking liaison workers by year and area.

Year	CSIRO Scientist (Hobart and Fremantle)	Contracted Japanese Speakers		
		Cape Town	Sydney	Brisbane
1991	8	0	0	0
1992	105	0	41	19
1993	115	72	37	10
1994*	93	111	30	2
Total	321	183	108	31

* through September 1994

3) promotion and direct recovery of tags by Australian Fishing Zone (AFZ) observers while on board vessels. In the 1990s, observer coverage within Australian waters has been about 10-20% of the total effort within the zone during the 1990s compared to very low levels of coverage in the 1980s. There has also been limited high seas observer coverage in the 1990s under the collaborative international Real Time Monitoring Program (RTMP);

4) personal port visits by contracted Japanese speaking liaison officers in Cape Town similar to those conducted in Australia (Table 3). Because of administrative constraints, these officers are only allowed to visit approximately 20-30% of the Japanese longline vessels stopping in Cape Town;

5) rapid (often immediate) and direct feedback to tag finders in terms of rewards and tag certificates with increased release/recapture information. Thus, rewards are given directly at time of tag collection during vessel visits and tag certificates are being faxed directly to vessels while at sea when the recovery of tags is reported by observers via radio;

6) direct presentations and discussions during pre-season meetings in Hobart with fishing masters and captains in 1992 and 1993 (about 30 attended each year);

7) direct contact with Japanese industry port agents from both the Federation of Japan Tuna Fisheries Cooperative Associations and National Ocean Tuna Fishery Association (ZENGOYREN). This has resulted in their cooperation in the distribution of promotional material, arranging contacts with vessels and collection of tags;

8) placement of advertisements in Japanese in the fax newspaper which is distributed regularly to Japanese longline vessels. These were prepared and sponsored directly by the Federation of Japan Tuna Fisheries Cooperative Associations;

9) visits in Japan by CSIRO scientists with Japanese researchers and scientific port agents that have direct contact with Japanese longline vessels when they return to Japan. This has resulted in increased cooperation in tag promotion and collection;

10) direct contact with New Zealand scientist and fishing organizations which has also resulted in their cooperation in the distribution of promotional material and collection of tags.

In spite of the above efforts, it is still recognised that there is a need for increased and improved promotional activities, particularly with respect to getting the information and rewards back to the actual crew members aboard Japanese longliners involved in landing the fish.

2.2.3 Other fisheries

No promotional activities were carried out in the 1980s for other fisheries that are known to harvest or are suspected of harvesting SBT (see Caton, 1994). In the 1990s, the port visitation program in Cape Town has also included 143 visit to Taiwanese longline vessels using that port. Also, Indonesian authorities have been informed about the program and CSIRO scientists have direct contact with Indonesian tuna industry and research organizations through a joint research program being conducted on SBT in Indonesia. Tagging posters have been translated into Indonesian and distributed. To-date, no tags have been recovered from either Taiwanese or Indonesian vessels. However, it should be noted that the Indonesian vessels are fishing on the spawning grounds and that the size and age of fish being caught are greater than the size and expected age of the largest tagged fish currently at liberty from the 1990s experiments.

2.3 Estimation of the Age Compositions of the Commercial Catch and Tagged Fish

In the results presented below, estimates of the reported recapture rate by cohort per 1000 fish harvested are made for various components of the SBT fisheries. The values used for the estimated number of fish caught per cohort in a given year were based on the procedures developed for estimating the age-composition of the catch for input into the virtual population assessments of the SBT stock (Polacheck et al., 1994; Hearn, 1994; Klaer and Polacheck ,1993). The estimation of age was based on a knife-edge partitioning of estimated length frequency distributions of the catch using a two stanza von-Berlalanffy growth curve. The growth parameters used here are for the "base" case and take into account increased growth rates of SBT in the 1980s compared to the 1960s (Anon, 1994, Hearn, 1994). The same age estimation procedure was used to assign tagged fish to cohorts based on their measured length at release. Results by area of the estimated reported recapture rates per 1000 fish harvested are also presented for the Japanese longline fishery. These results use the main statistical areas that have been defined for reporting SBT catches (Figure 2).

The statistical properties of these reported recapture rates are not straight forward. If one assumes that the recapture process is essentially random within a fishery (i.e., complete mixing of tagged and untagged fish), then the recovery process can be considered to be approximately a Poisson process. In this case, the coefficient of variation in the recovery rates conditional on the estimated total number of fish harvested is a simple function of the actual number of tags recovered. The problem in determining an unconditional variance is that variance and sampling distribution associated with the estimates of the total number of fish harvested from a cohort (i.e., the denominator in the estimated recovery rate) are not known. Table 4 provides the calculated coefficient of variation assuming that the recovery process is Poisson and conditional on the estimated total number of fish harvested as a guide to the minimum level of uncertainty associated with these recovery rate estimates.

Table 4. Calculated coefficient of variation for estimates of tag recovery rates based on the number of tags recovered conditional on the estimated number of fish harvested and assuming that the recovery process is Poisson.

Number of tags returned	Coefficient of variation
1	100%
2	71
3	58
4	50
5	45
10	32
20	22
30	18
40	16
50	14
75	12
100	10

3. RESULTS - EVIDENCE FOR INTERACTIONS

3.1 1983/84 Tagging Results

Of the 10,188 fish tagged in the 1983/84 tagging experiment 4,135 tag recaptures were reported to CSIRO. Ninety-nine percent of these were caught in the surface fishery and only 57 (1.4%) were reported by Japanese longline vessels (Table 5). Overall, there were very few reported longline recaptures in the waters around Australia and the first reported longline recaptures in combined statistical areas 4 and 7 occurred in 1987 (Table 6).

Some 94% of all the reported recaptures were estimated to belong to the 1982 and 1983 cohorts (Table 7). Comparison of the estimates of the tag recovery rates from these two cohorts for the period from 1984 through 1987 between the Japanese longline fishery and Australian surface fishery indicate a substantially greater recovery rate in the surface fishery than in the Japanese longline fishery (Tables 8 and 9). Thus, tag recovery rates per

1000 fish caught were generally between 3 and 10 times greater in the surface fishery. Furthermore, as the tagged fish aged and became less available to surface fishery, there is no indication of a decline in the discrepancy in the recovery rates between 1984 and 1987 in the two fisheries during this period. If anything, the discrepancy became greater. Overall, only about 17% of the expected number of tags were recovered from the Japanese longline fisheries for the 1982 and 1983 cohorts between 1984 and 1987 based on the estimated recovery rates from the Australian fishery and estimated number of longline caught fish from these cohorts[3].

Table 5. The number of reported recaptured tagged fish by year and fishing gear from the 1983/84 tagging program.

	Number of Recaptures	
Year	Longline	Surface
1983	0	1409
1984	7	1393
1985	11	808
1986	6	410
1987	9	55
>1987	24	3

Table 6. Number of reported recaptures of tagged fish from the 1983/84 tagging experimented by Japanese longliners by statistical area and year.

	Number of Recaptures				
year	Area 4	Area 5/6	Area 7	Area 8	Area 9
1984	0	0	0	6	1
1985	0	0	0	5	6
1986	0	1	0	2	3
1987	2	0	0	0	7
1988-90	1	0	5	1	3
1991-94	0	2	6	4	2

[3] The total expected number of recaptures was calculated by multiplying the observed recovery rate for a cohort in given year in the domestic surface fishery by the corresponding estimated catch by the Japanese longline fleet and summing these across the 1982 and 1983 cohort for the years 1994-87.

Table 7. The percentage of recaptured tagged fish from the 1983/84 tagging program which are estimated to have belonged to the 1982 and 1983 cohorts based on their measured length at release.

Year of Recapture	Cohort		Total number of recaptures with release lengths
	1982	1983	
1983	94.3%	3.2%	1,404
1984	48.9	49.3	1,494
1985	43.9	53.3	816
1986	33.0	65.8	415
1987	46.9	50.0	64
>1987	40.7	44.4	27

Table 8. Tag recovery rates (i.e., number of reported tag fish recovered per 1000 fish harvested from that cohort) that belonged to the 1982 cohort based by year of recapture and gear.

Year	Surface	Longline
1984	1.41	0.94
1985	2.69	0.21
1986	3.75	0.41
1987	4.20	0.87

Table 9. Tag recovery rates (i.e., number of reported tag fish recovered per 1000 fish harvested from that cohort) that belonged to the 1983 cohort based by year of recapture and area.

Year	Surface	Longline
1984	0.86	0.00
1985	1.43	0.50
1986	1.41	0.15
1987	0.88	0.14

There were no longline tag recoveries between 1983 and 1987 from any year class in areas 3 and 7 (see Figures 2 and 3, and Table 6). These statistical areas adjoin the surface fisheries and tagging areas in Western and South Australia (note that there was no longline effort or catch reported in area 3 in these years). The longline fishery in these areas was small during this period and only a total of an estimated 1,935 and 1,289 fish were harvested during this period from these two areas by Japanese longliners from the 1982 and 1983 year classes. Nevertheless, based on the recapture rates in the surface fishery, approximately 7 tags would have been expected to have been recovered in these area if in fact the tagged fish were uniformly mixing between the two fisheries. It is worth noting that during the period since 1988 a total of 11 tags have been recovered from area 7 (more than from any of the other statistical areas). While the estimated number of fish harvested in these areas from the 1982 and 1983 cohorts was relatively small, the recovery rate from

1988 through 1990 remained low (0.46 per thousand fish caught based on five recoveries from an estimated catch of nearly 11,000 fish). Coinciding with the commencement of the current tagging program in late 1990, there has been a marked increase in the recovery rate of 1983/84 tagged fish (2.84 based on five recoveries from an estimated catch of nearly 1,800 fish).

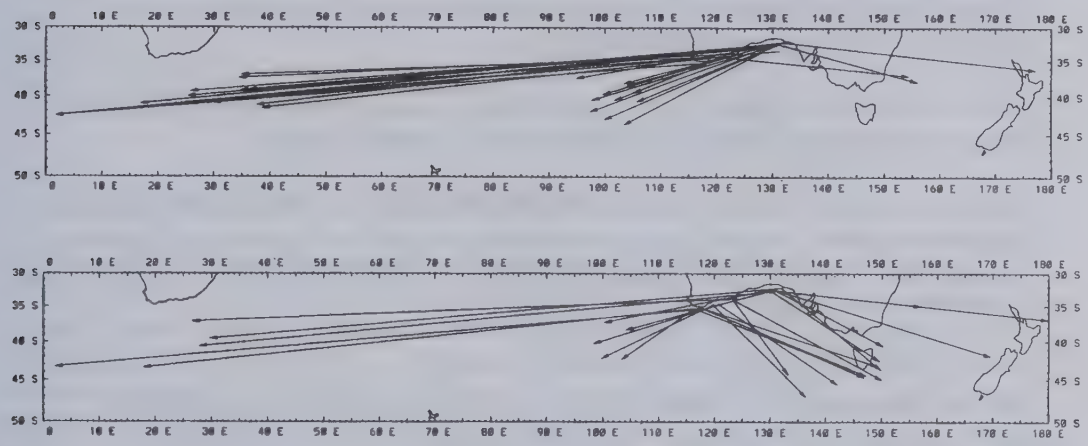

Figure 3. Release and recapture locations of tagged fish from the 1983/84 experiment by Japanese longline vessels; a (top) recaptures through 1987, b (bottom) recaptures after 1987.

3.2 1990s Tagging Results

The results with respect to implications for interactions between surface and longline fisheries are substantially different for the 1990s experiment compared to the 1980s. Of the 42,832 fish that were tagged off Western and South Australia, 1498 of these have been recaptured as of 21 November 1994 (i.e., 3.5% to date compared to the 40.5% total for the 1983/84 releases). The large difference in the magnitude of the return rate reflexes both the imposition of restrictive catch quotas and a shift in the fishery towards larger fish. However, the relative distribution of recaptures between surface and longline gear does not show the large discrepancy that was observed in the 1980s. Thus, approximately 44% of the reported returns have been recaptured using longline gear (Table 10) and these have come from all of the Japanese longline statistical areas in which significant numbers of juvenile SBT are currently harvested (Table 11). There have been major changes in the SBT fishery that have contributed to this difference (see Caton, 1994; Caton et al., 1995; Nishida, 1994, for more detail). These include:

1) a large decrease in the absolute size of the surface fishery (from around 20,000 mt to about 2,000 mt) including the near cessation of any commercial catches in western Australia;

2) a decrease in the size of the surface catches relative to the global longline catches, particularly for juvenile fish. (Thus, in 1993, the surface fishery caught only 46% of the total number of age 2 to 4 year old fish compared to 90% in 1984);

3) the development of a small (approximately 250 mt) Australian domestic longline fishery, primarily off New South Wales;

4) the introduction of restrictive catch quotas for the Australian, Japanese and New Zealand fleets (there has been a subsequent increase in catches by other parties - particularly by Taiwan and Indonesia);

5) seasonal and area changes in the distribution of Japanese longline effort with a major concentration of effort in the winter fishery around Tasmania.

6) the development of joint venture arrangements among Australian quota holders and Japanese longliners resulting in increased summer and winter longlining by Japanese vessels within Australia's AFZ, especially adjacent to Tasmania and the southwest coast of Australia.

Overall these changes have meant that Japanese and joint venture longliners are catching somewhat greater numbers of juvenile fish than Australian surface fisheries. As such, these differences would be expected to increase the relative proportion of longline returns compared to surface returns. However, as detailed below, these changes in the fishery do not appear to be a sufficient explanation for the differences.

Table 10. Number of tag recoveries to date from releases off Western Australia and South Australia from the 1990s tagging experiments by year, gear and vessel nationality.

Year	Australian		Japanese Longline	Total
	Surface	Longline		
1991	165	3	52	220
1992	206	18	131	355
1993	229	33	223	485
1994	251	47	152	450
Total	852[1]	101	558	1,512

1) one tag was recovered in the Australian surface fishery for which it was impossible to ascertain even an approximate date of recapture.

Table 11. Number of reported recaptures by Japanese longline vessels from tagged fish released off Western Australia and South Australia in the 1990s by statistical reporting area (Figure 2) and year.

	Statistical Area						
Year	2	4	5	6	3 & 7	8	9
1991	0	1	0	1	36	10	3
1992	0	11	0	5	89	22	3
1993	0	38	3	0	135	18	26
1994*	1	15	0	2	80	27	28
Total*	1	65	3	8	340	77	60

* through November 1994

3.3 Movements Between Fisheries and Areas

Data on the release and recapture position of tagged fish provide one of the only sources of direct information on fish movements and thus the potential interactions between spatially disjoint fisheries. Results on the movement of SBT tagged in 1990-94 are presented in Figures 1 and 4 to 8. Each arrow indicates the release and recapture position of one recaptured fish. The level of fishing effort and catch in different areas needs to be considered when interpreting these maps. Fishing effort is highly seasonal for all areas where tagged fish have been recovered. In the 1990s, the only substantial surface fishery for SBT occurs off South Australia in the Great Australian Bight in the austral summer and autumn with small amounts of trolling activity off eastern Tasmania.

As was found in previous tagging studies, these maps indicate that there is a relatively rapid movement of fish from the surface fishery in Western Australia to the surface fishery in South Australia and that these fish remain vulnerable for up to four years after being tagged (Figure 4). However, a feature not found in previous studies (in part due to the lack of a substantial fishery off Tasmania) is the very rapid southeast movement of fish from both South Australia and Western Australia into the longline fishery off eastern and southern Tasmania (Figure 5). Fish tagged off South Australian in February are caught by offshore Japanese longline vessels fishing off Tasmania in May and June of the same year that they were released. (Note that the longline season off Tasmania has begun somewhere between early May and early June during 1991-94.) There also appears to be a relatively rapid movement of fish from Western Australia to Tasmania with a number of fish being caught off Tasmania within six months from their time of release in Western Australia. The number of short term recaptures from Western Australia is less than the number from South Australia. This probably reflects size related differences in movement patterns and possibly gear selectivity.

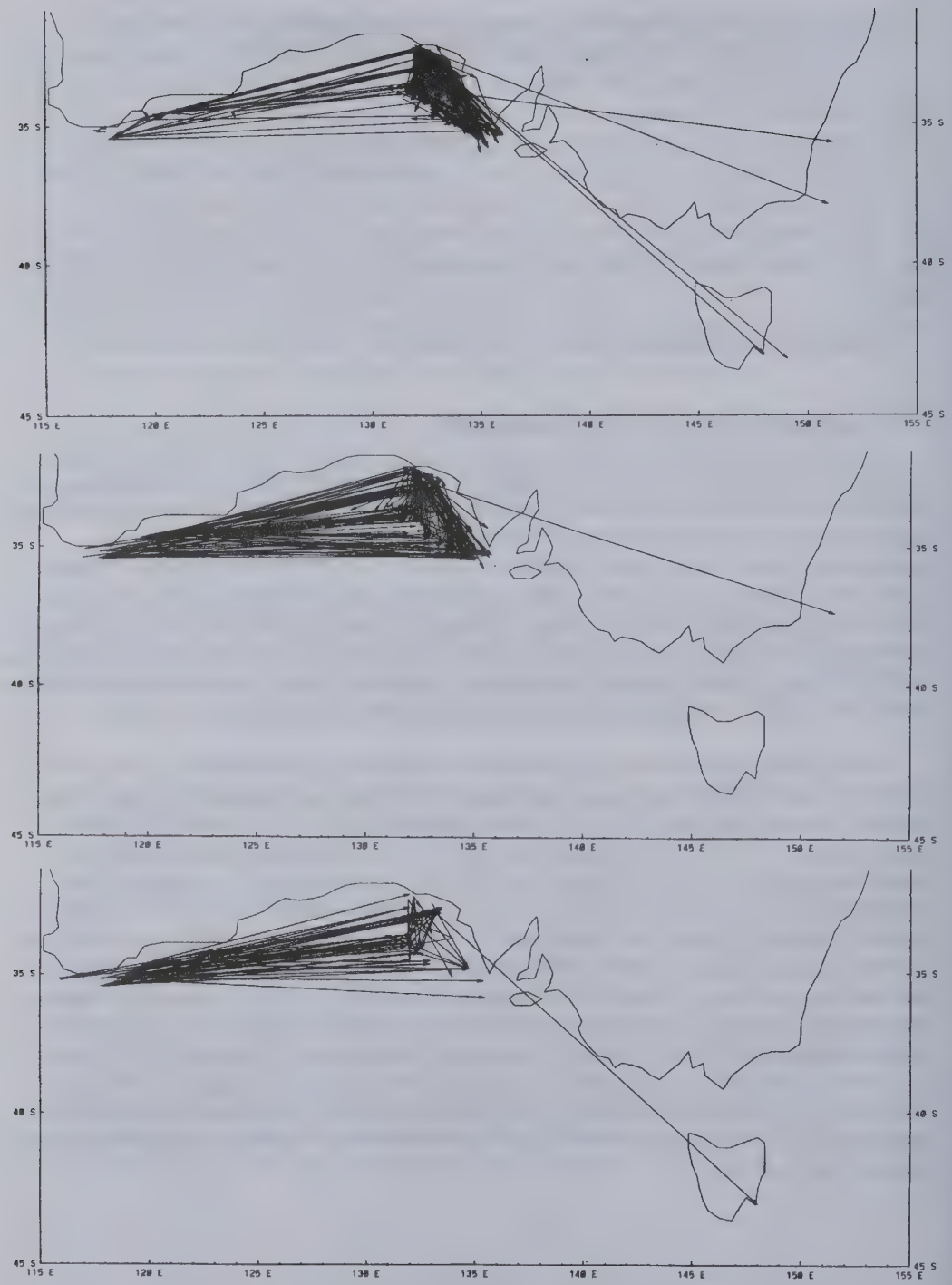

Figure 4. Release and recapture locations of surface tagged fish from Western and South Australia recaptured by surface gear from the 1990s tagging experiments; a (top) recaptures with time at liberty less than 1 year, b) recaptures with time at liberty between 1 year and two years, c (bottom) recaptures with time at liberty greater than 2 years.

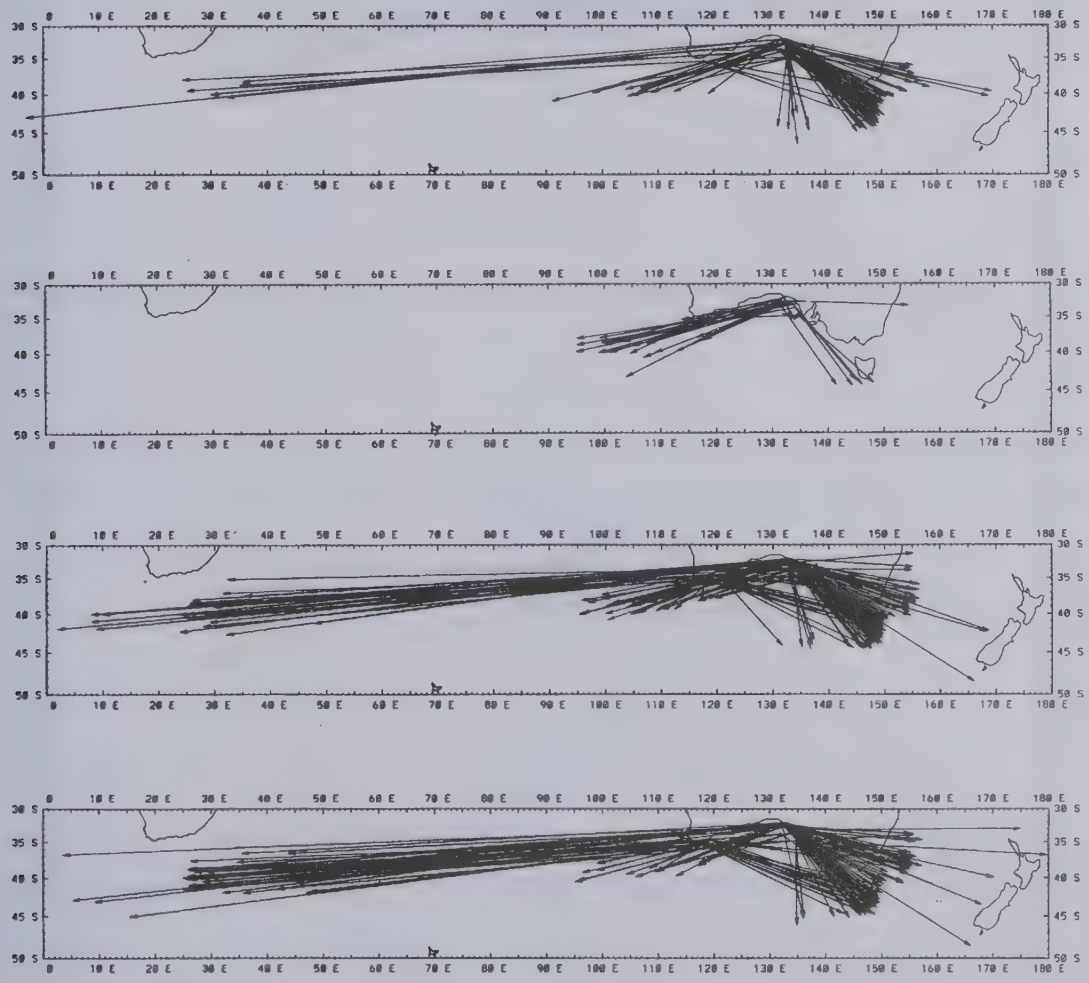

Figure 5. Release and recapture locations of surface tagged fish from Western and South Australia recaptured by Japanese longline vessels (including joint venture operations) from the 1990s tagging experiments; a (top) recaptures with time at liberty less than 7 months, b) recaptures with time at liberty between 7 and 12 months, c) recaptures with time at liberty between 1 year and two years, d (bottom) recaptures with time at liberty greater than 2 years.

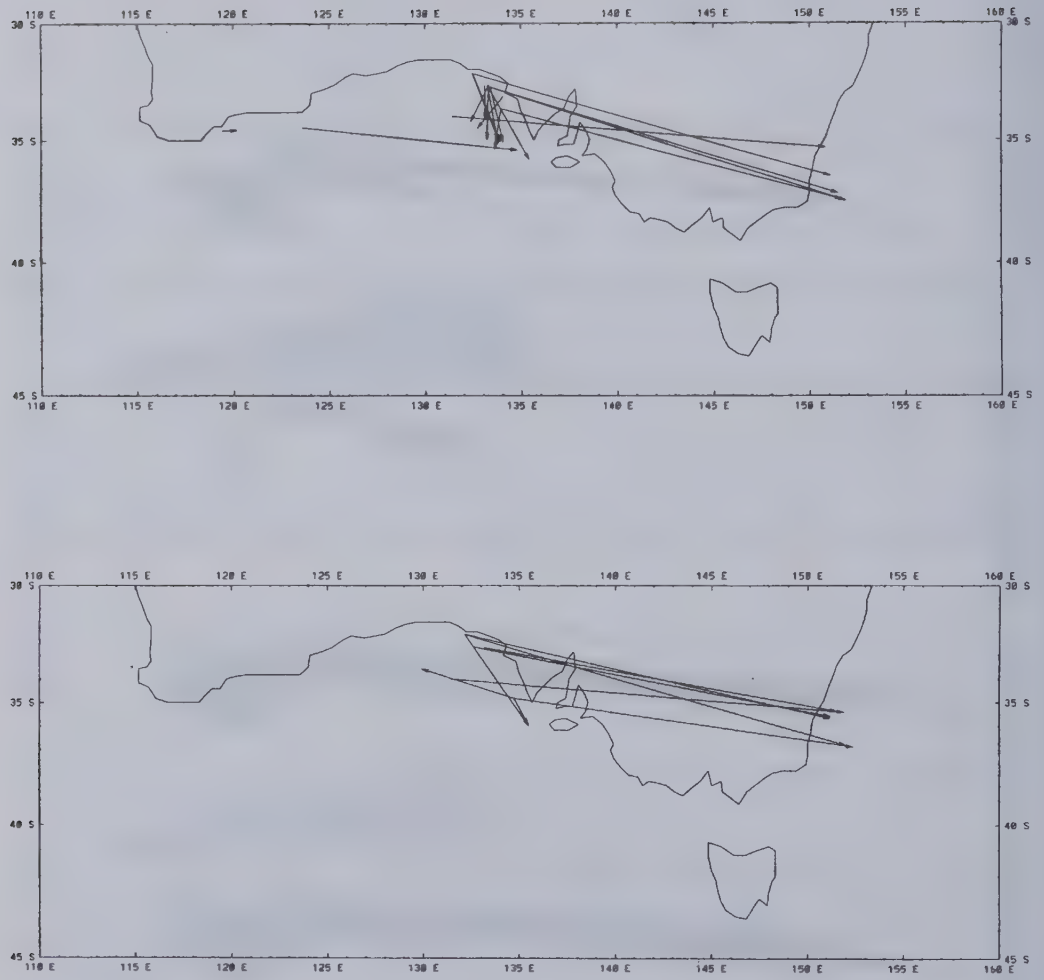

Figure 6. Release and recapture locations of surface tagged fish from Western and South Australia recaptured by Domestic Australian longline vessels from the 1990s tagging experiments; a (top) recaptures with time at liberty less than 7 months, b (bottom) recaptures with time at liberty between 7 and 12 months.

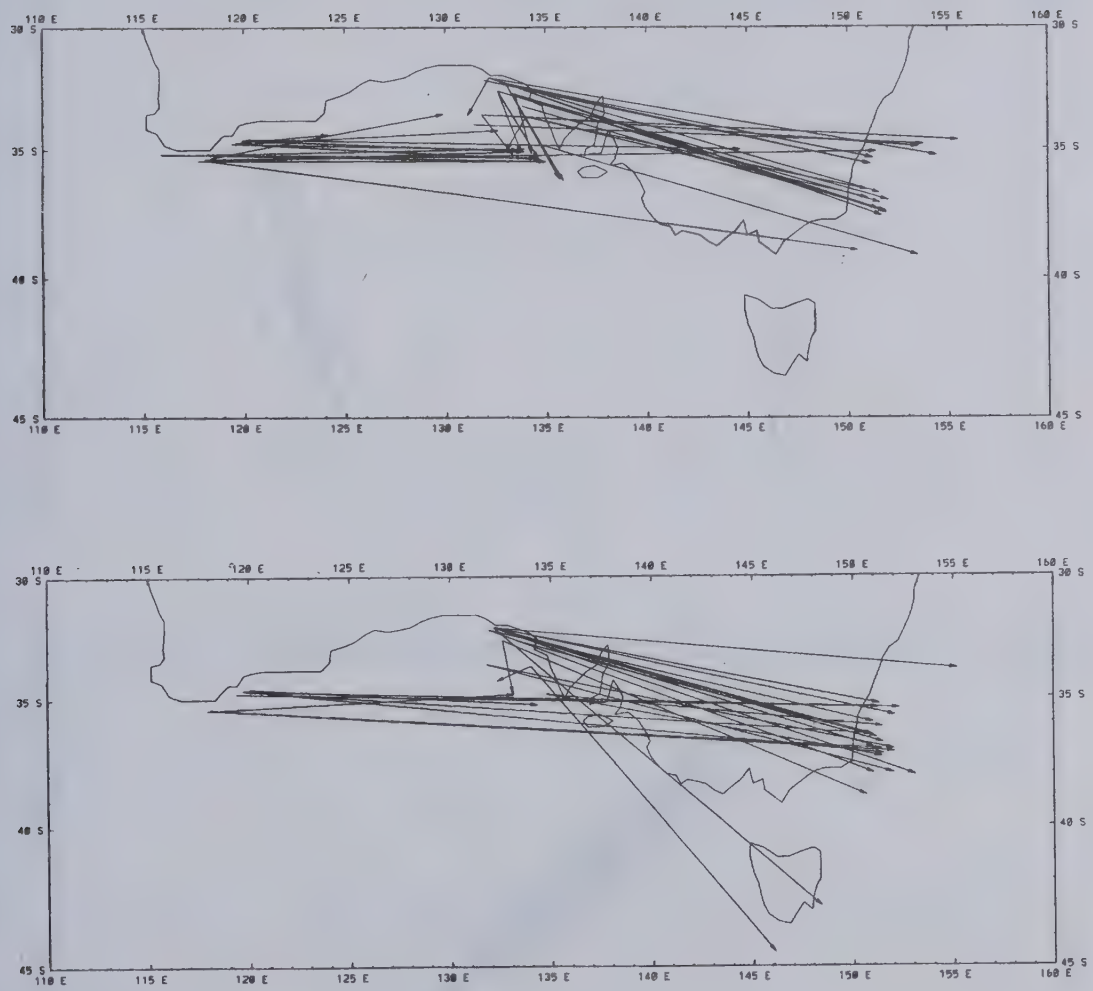

Figure 6 (continued); c (top) recaptures with time at liberty between 1 year and two years, d (bottom) recaptures with time at liberty greater than 2 years.

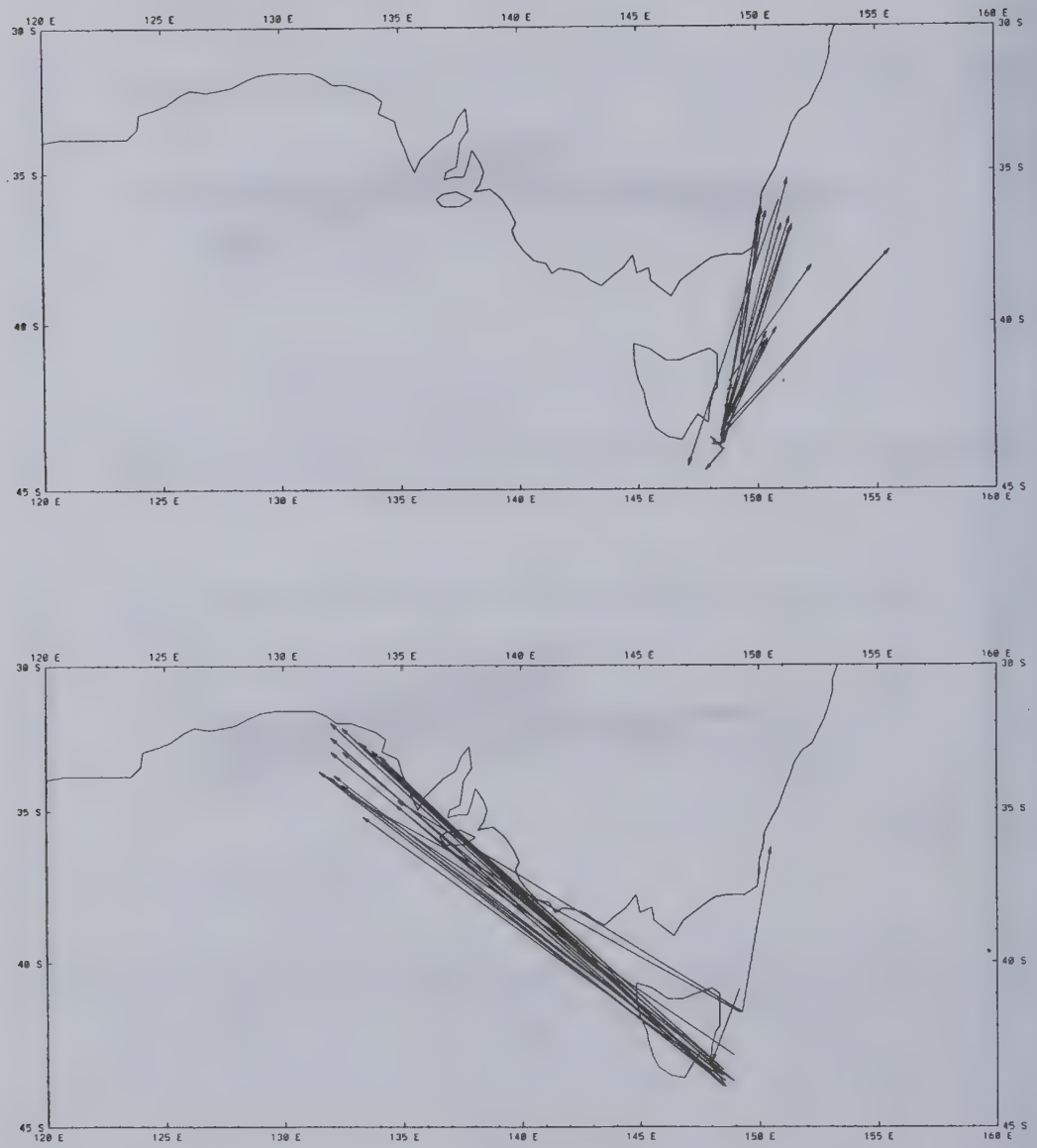

Figure 7. Release and recapture locations of longline tagged fish recaptured from the 1990s tagging experiments; a (top) recaptures with times at liberty less than 1 year by longline vessels, b (bottom) recaptures with times at liberty less than 1 year by surface gear.

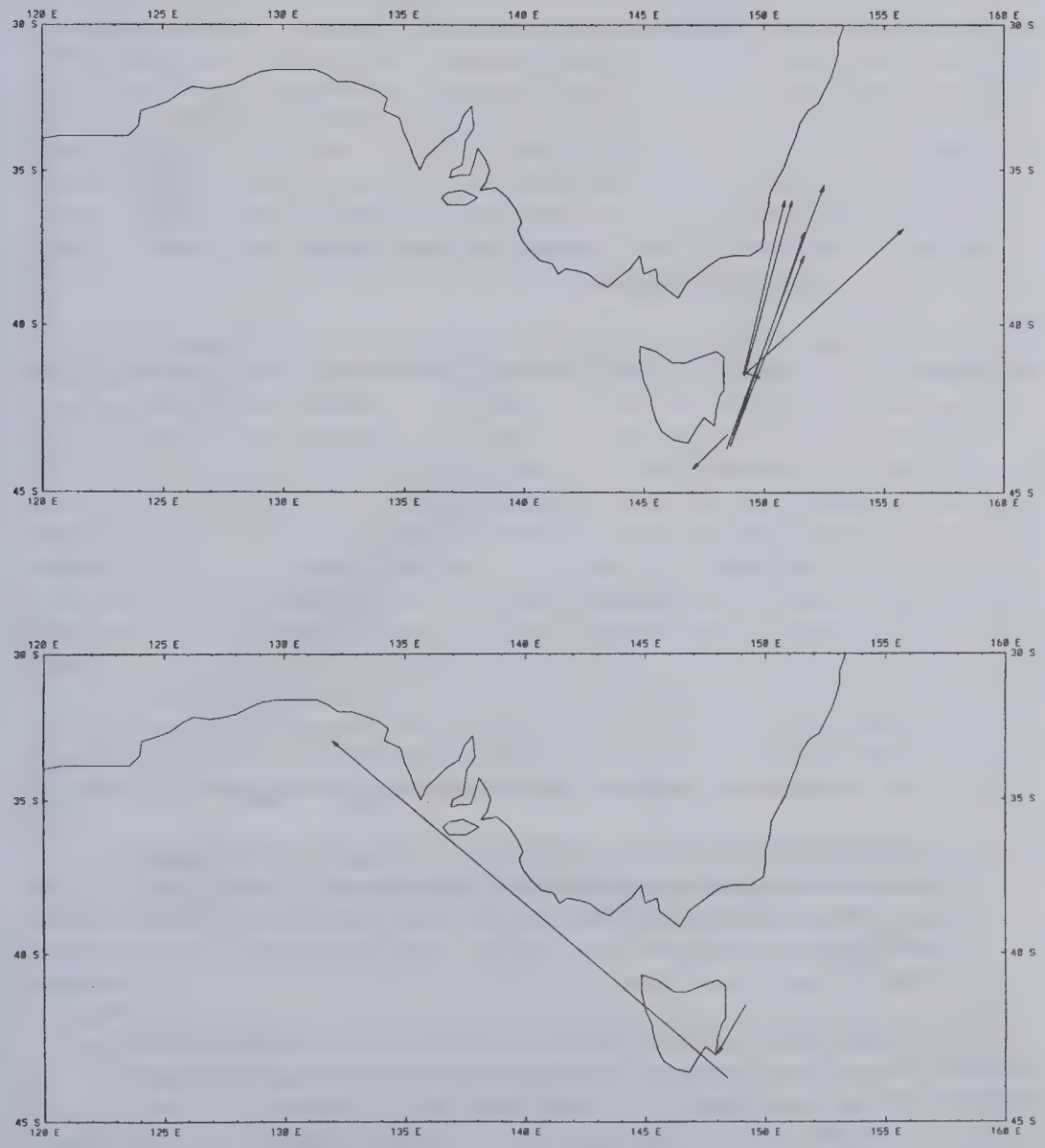

Figure 7 (continued); c (top) recaptures with times at liberty greater than 1 year by longline vessels, d (bottom) recaptures with times at liberty greater than 1 year by surface gear.

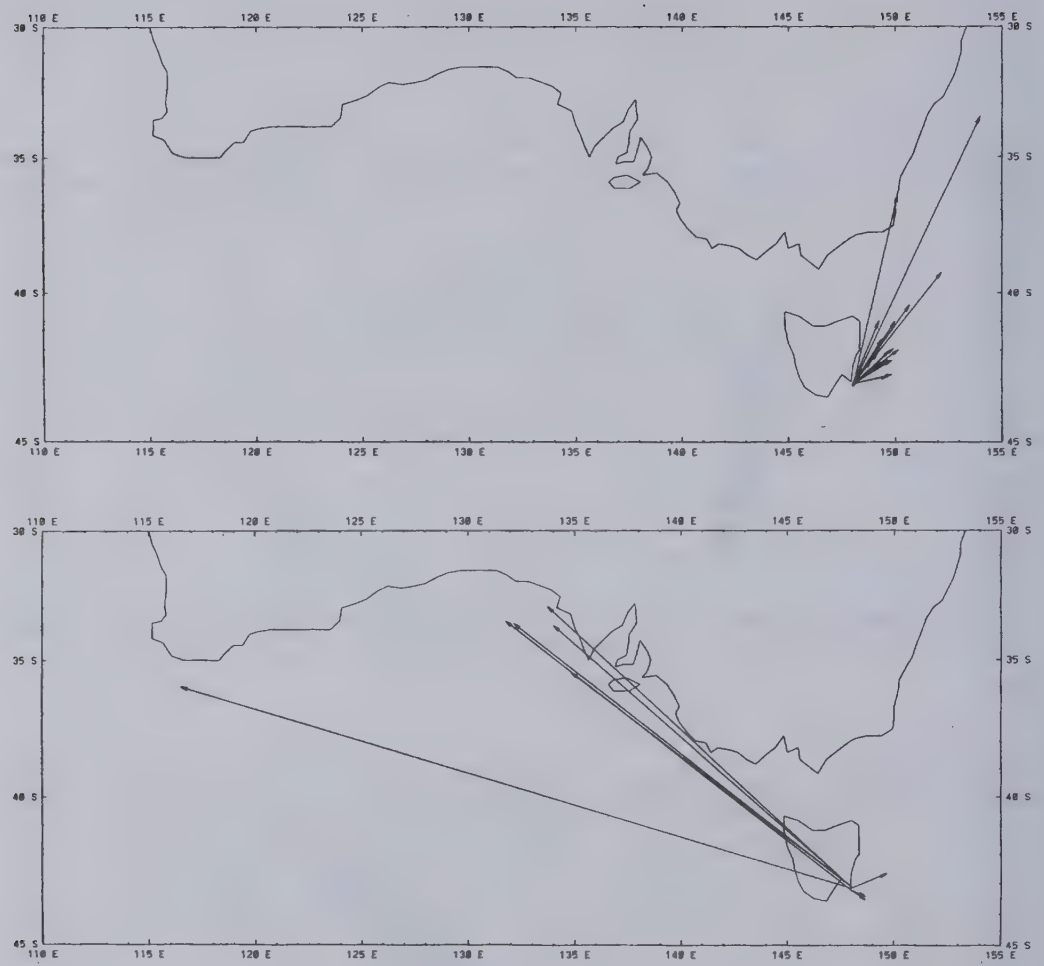

Figure 8. Release and recapture locations of troll-caught fish tagged of eastern Tasmania from the 1990s tagging experiments; a (top) recaptures with times at liberty less than 4 months, b (bottom) recaptures with times at liberty greater than 4 months.

The rapid movement of surface tagged fish into the Japanese longline fisheries is not confined to waters around Tasmania. A large number of the fish tagged off South Australia have also been caught by longliners fishing to the southwest of Western Australia (Figure 5). However, few fish have been caught in this area by Japanese longliners from the releases of predominantly younger aged fish in Western Australia. There have also been a number of short-term recaptures from releases in South Australia caught by the Japanese fleet operating off South Africa. For example, two fish (released in 1991) were caught off South Africa less than 6 months after their release off South Australia. A total of seven recoveries have been reported off South Africa within one year of release from Western or South Australia.

The spatial distribution of tag returns from Japanese longliners for fish that have been at liberty greater than one year compared to tagged fish which were recovered within one year of release are similar except for an increase proportion being recovered off South Africa for longer times at liberty.

The development of the domestic Australian longline fishery has resulted in a substantial number of recaptures. This is somewhat surprising given the small size of this fishery (less than 350 mt per year or between 1 and 22% of the annual surface catch in the 1991-93 period). There is a rapid movement of surface tagged fish within the Great Australian bight into the longline fishery just off the shelf of the bight (Figure 6). Thus, there have been 12 recaptures of surface tagged fish by domestic Australian longliners within 3 months of their release with the shortest time at liberty being 16 days. Also, 12 out of the 56 recaptures of surface tagged fish by Australian longliners fishing off the east coast of Australia have occurred during the domestic longline fishing season during the same year (May to November) in which the fish were tagged (Figure 6).

The tag recaptures from the pilot longline release off-eastern Tasmania also indicate a movement of tagged fish into the surface fishery off South Australia (Figure 7, Table 12). Thus, tagged fish were recovered during the next season in South Australia after tagging (i.e., longline fish were released in late May and June and the South Australia season begins in late December/early January). Previous to these pilot longline releases, the movement of SBT has generally been considered to be uni-directional such that once fished entered the longline fishery there was no substantial movement back into the Australian surface fisheries (e.g., Majkowski et al., 1988; Caton, 1991; Hampton, 1991). The results from these longline releases are the first evidence of substantial movement of SBT from longline fishing grounds into surface fisheries. However, results reported by Shinju (1978) based on the recovery of two tags in the surface fishery off South Australia from 52 release in 1977 from a longliner operating southwest of Australia provided some previous indication that such movements were possible. The prior lack of evidence was due to the lack of opportunities to tag fish aboard longline vessels and the results illustrates the importance of being able to tag fish from all areas in which fisheries occur.

There has also been a single recapture in both the troll fishery off eastern Tasmania and the New South Wales recreational fishery from these longline releases. In addition, there has also been the recaptures of longline released fish by both Japanese and Australian longline vessels. However, to date, all of these have been from the waters around southeast Australia with no longline recaptures from either the southeast Indian Ocean or South Africa.

Table 12. Number of tags recovered from pilot tagging experiments off eastern Tasmania based on recoveries through November 1994.

		1991 Releases from Troll Caught Fish	1992 Releases from Longline Caught Fish	1993 Releases from Longline Caught Fish	1993 Releases from Troll Caught Fish
Number released		86	88	364	33
Total Number recaptured		15	11	45	12
Fleet	Time at Liberty				
Japanese Longline	<30 days	12	0	5	5
	>30 days	1	2	5	5
Australian Longline	<30 days	0	0	2	0
	>30 days	0	3	8	1
Australian Surface	<30 days	0	0	0	0
	>30 days	2	6	25	1
Mean release length		89.1 (s.e. = 0.21)	90.4 (s.e. = 0.56)	93.6 (s.e. = 0.30)	94.3 (s.e. = 0.96)
First release date		28/5/91	10/6/92	29/5/93	28/4/93
Last release date		19/6/91	14/6/92	11/6/93	2/6/93

The small scale tagging of troll-caught fish in the inshore waters off eastern Tasmania resulted in a relatively large proportion of these surface caught fish being caught in the adjoining Japanese longline fishery off eastern Tasmania (Figure 8, Table 12). Thus, 12 out of 86 fish tagged in 1991 were recaptured by Japanese longline vessels within 30 days of their being released and 5 out of the 34 releases in 1993. This suggests a high degree of interaction and movement between the surface and longline fishery in this area and time period. Similar to the recapture of longline tagged fish from eastern Tasmania, all recaptures to date from these surface releases off eastern Tasmania have been from waters around Australia. Overall, the recoveries of tagged fish released off Tasmania indicate rapid and significant interaction between the inshore and adjoining offshore fishery around Tasmania.

3.4 Comparative Recovery Rates

The estimated cohorts for which tag recoveries have come from the 1990s experiments are spread across the 1988 to 1992 cohorts (Table 13) with the largest fraction (43%) coming from the 1990 cohort. Estimates of the recovery rate of tagged fish from these various cohorts by area and year can be calculated for 1991 to 1993 (at the time of drafting this paper, the catch data were not yet available for 1994 while the catch statistics for 1993 were preliminary estimates).

Comparison of the tag recovery rate per thousand fish caught for the Japanese longline fleet and the Australian domestic surface fishery for the 1990s tagging experiments suggest a very different picture than the rates observed in the 1980s (Tables 14 and 15). Thus, the rates for the two fisheries in the 1990s are of the same order of magnitude and the surface recovery rates are generally less than twice as large as rates in the longline fishery. The one exception is for the recovery rate of two year old fish in 1993 (16.86 versus 0.0). However, this rate is based on only 13 recoveries of small fish. Overall, the reported number of longline returns is between 55% and 67% of the expected numbers based on the

recovery rates for the Australian surface fishery and the estimated number of longline fish caught from each cohort and each year for the 1989 to 1991 cohorts. In addition, the relative recovery rates between the Japanese longline fishery and the Australian domestic surface fishery are similar for tagged fish recovered in the year that they were release and for those with longer times at liberty.

Table 13. The percentage of recaptured tagged fish from the 1990s tagging program which are estimated to have belonged to various cohorts based on their measured length at release.

	Recapture Year			
Cohort	1991	1992	1993	1994*
1988	17.4	1.1		
1989	68.9	49.3	1.6	0.6
1990	13.7	48.7	14.5	6.5
1991		0.8	56.1	37.1
1992			25.4	38.8
1993			2.5	14.9
no length				2.0

* recoveries through November 1994

Table 14. Tag recovery rates for the 1990s tagging program (i.e., number of reported tag fish recovered per 1000 fish harvested) from surface Australian fisheries by year and cohort. The numbers in parenthesis are the number of tags reported.

	Year recovered		
Cohort	1991	1992	1993
1988	0.30 (25)	0.00 (0)	0.00 (0)
1989	1.57 (99)	1.84 (101)	2.24 (12)
1990	0.47 (29)	4.16 (104)	3.26 (141)
1991	0.00 (0)	0.19 (2)	2.02 (63)
1992	-	0.00 (0)	18.76 (13)

Table 15. Tag recovery rates for the 1990s tagging program (i.e., number of reported tag fish recovered per 1000 fish harvested) from the Japanese longline fisheries by year and cohort. The numbers in parenthesis are the number of tags reported.

	Year Recovered		
Cohort	1991	1992	1993
1988	0.30	0.08	0.18
	(13)	(4)	(7)
1989	1.50	1.16	1.25
	(49)	(66)	(56)
1990	0.67	1.67	2.13
	(1)	(61)	(122)
1991	0.00	1.28	1.48
	(0)	(1)	(46)
1992	-	0.00	0.00
		(0)	(0)

An examination of the recovery rates by area from the Japanese longline fishery suggests that the tagged fish are dispersing and are vulnerable to being harvested in all of the major longline fishing areas. Thus, the recovery rates in all of the major SBT statistical areas in which juveniles are harvested are of the same order of magnitude as those in the surface fishery (Table 16). The recovery rates tend to be the lowest in area 9 and highest in area 8, although for the later the actual number of tags recovered is small reflecting the low catch rate of fish from cohorts of fish which have been tagged. (Note that the small number of tags recovered from New Zealand waters (areas 5 and 6 in Table 11) reflects the small number of juveniles that are caught in this area rather than any evidence for lack of interactions between surface and longline fisheries.

The recovery rates from the longline component of the Australian domestic fishery are generally higher than those from other areas of the Australian domestic fishery and from the Japanese longline fishery (Table 17 compared to Tables 14 and 15). The recovery rates from the domestic longline fishery exceed those from the Japanese longline fishery in the same areas (areas 3,4 and 7) by a factor of two to six. The domestic longline fishing season continues after the end of the Japanese season. As such, returns rates might be expected to be greater during the first season after release if mixing/diffusion of tag fish into the New South Wales area was still occurring. However, similar differences in the recovery rates also exist for tags which have been recovered with times at liberty exceeding one year (Table 18).

Table 16. Tag recovery rates for the 1990s tagging program (i.e., number of reported tag fish recovered per 1000 fish harvested) from the Japanese longline fisheries by year, cohort and statistical area. The numbers in parenthesis are the number of tags reported.

	Area 3 and 7			Area 4			Area 8			Area 9		
	1991	1992	1993	1991	1992	1993	1991	1992	1993	1991	1992	1993
1988	0.74 (11)	0.15 (2)	0.42 (3)	0.00 (0)	0.00 (0)	0.11 (1)	0.00 (0)	0.33 (1)	0.00 (0)	0.13 (2)	0.00 (0)	0.05 (1)
1989	2.11 (35)	1.70 (47)	2.06 (27)	0.50 (2)	0.56 (4)	1.46 (14)	1.15 (9)	2.07 (9)	2.40 (5)	0.26 (1)	0.18 (3)	0.41 (8)
1990	0.00 (0)	1.57 (41)	2.60 (72)	0.00 (0)	1.15 (7)	1.74 (22)	1.08 (1)	3.62 (12)	2.85 (10)	0.00 (0)	0.00 (0)	1.27 (16)
1991	-	0.00 (0)	1.86 (39)	0.00 (0)	0.00 (0)	0.73 (2)	-	0.00 (0)	0.99 (4)	-	0.00 (0)	0.99 (1)
1992	-	0.00 (0)	0.00 (0)	-	-	0.00 (0)	-	-	0.00 (0)	-	-	0.00 (0)

4. DISCUSSION

The results from the most recent SBT tagging experiments suggest very different conclusions about the potential for significant interaction between longline and surface fisheries than the results from previous SBT tagging studies[4] or from tagging studies on other tuna. The results suggests rapid and significant interchange of fish between the two fisheries as evidenced both by the relative recovery rates from the two types of gear (e.g., Tables 14 and 15) and by the spatial and temporal distributions of the recoveries (Figures 1 and 4 to 8). The mixing between surface and longline fisheries in essentially the same area is apparently very rapid based on the results off eastern Tasmania and on the returns from domestic Australian longliners off South Australia. However, even for spatially disjoint fisheries, there is significant interchange occurring within 3 to 6 months of surface tagged fish being released. Substantial number of surface tagged fish from Australia are being recovered in longline fisheries as distant as South Africa. In addition, the limited results from longline tagging indicate that mixing occurs not only from surface fisheries into the longline fisheries but from longline fisheries into surface fisheries. The results do not

[4] It should be noted that a large tagging program for SBT was also conducted throughout the 1960s. A thorough analysis and presentation of the results from this programs was beyond the scope of the present paper and any analyses of the 1960s tagging results in terms of the recovery rates by cohort for the Japanese longline fishery would have greater uncertainty than those from the 1983/84 and 1990s programs presented here. There is greater uncertainty in interpretation because (1) a large fraction of the longline effort (over 50%) took place either in the spawning or spawning staging grounds (areas 1 and 2 in Figure 3) prior to 1966 and(2) concerns exist about the reliability of the length frequency data for the commercial catch prior to 1966 while 56% of the 1960s tag releases occurred prior to 1966. However, comparisons of the overall relative recovery rates by cohort from the Australian surface and Japanese longline fishery yielded similar results and a similar overall view of the potential interactions between these two fisheries as those from the 1980s.

support any previous speculations that the surface and sub-surface fish may constitute biologically or behaviourally different components of the stock.

Table 17. Tag recovery rates for the 1990s tagging program (i.e., number of reported tag fish recovered per 1000 fish harvested) from the Australian domestic longline fisheries by year and cohort. The numbers in parenthesis are the number of tags reported.

	Year Recovered		
Cohort	1991	1992	1993
1988	0.00 (0)	0.00 (0)	0.86 (1)
1989	-	10.40 (10)	2.57 (5)
1990	-	18.74 (8)	4.62 (17)
1991	-	-	4.62 (11)
1992	-	-	0.00 (0)

Table 18. Comparison of tag recovery rates (i.e., number of reported tag fish recovered per 1000 fish harvested) between the Australian domestic longline fishery and the Japanese longline fisheries in the same areas for recoveries which occurred subsequent to the year in which the fish were tagged by year and cohort.

		Year Recovered	
Fishery	Cohort	1992	1993
Australian	1988	0.00	0.86
Domestic	1989	8.32	2.57
Longline	1990	9.37	4.08
	1991	-	2.10
	1992	-	0.00
Japanese	1988	0.15	0.42
Longline	1989	1.31	1.99
Areas 3 & 7	1990	0.46	2.13
	1991	0.00	0.24
	1992	0.00	0.00
Japanese	1988	0.00	0.11
Longline	1989	0.28	1.46
Area 4	1990	0.49	1.34
	1991	0.00	0.00
	1992	-	0.00

Furthermore, recent results on the swimming and diving of SBT also suggest that the variation in behaviour exhibited by individual fish would indicate that individuals would be vulnerable to capture by both surface and sub-surface gear. Thus, both sonar tracking and archival tag results have shown that within a single day fish make frequent and large changes in the depth at which they are swimming (Davis, 1993, 1994a, 1994b; Gunn et al., 1994). Periods of prolong times at the surface are occur almost exclusively in the late mornings and afternoons. Figure 9 is an example of the depth distribution within a single day for a juvenile SBT off the shelf of the Great Australian Bight based on data collected with an archival tag. The fish utilizes and "explores" a wide range of depths from the surface to over 100 m. This fish was caught twice (i.e., when first tagged and subsequently when recaptured) by surface gear. Data from the archival tag strongly suggests that during the interim period that it was feeding at depth.

The critical question in interpreting the difference in the 1983/84 tagging results with those from the 1990s is what is the reason for the much higher recovery rate from longliners in the 1990s. The fundamental difference does not appear to be biologically or fishery related but appears to be the result of a much higher reporting rate of recaptured tagged fish as a result of improvements in the promotion of tag recoveries. Thus, there has not been any fundamental change in how the Japanese longliners set their gear (e.g., depth of setting, hook size, baits, etc.) and it is hard to conceive of any factor that could result in a major behavioural change in feeding/vulnerability of the tagged SBT to longlining. As noted above, there have been seasonal and area shifts in the distribution of longline efforts. However, for this to explain the difference in the recovery rates would require a

substantially disproportional higher occurrence of tagged fish in these areas/seasons relative to untagged fish of the same size/age. In contrast, there have been very substantial changes in the efforts and methods used to increase the reporting rate from Japanese longliners.

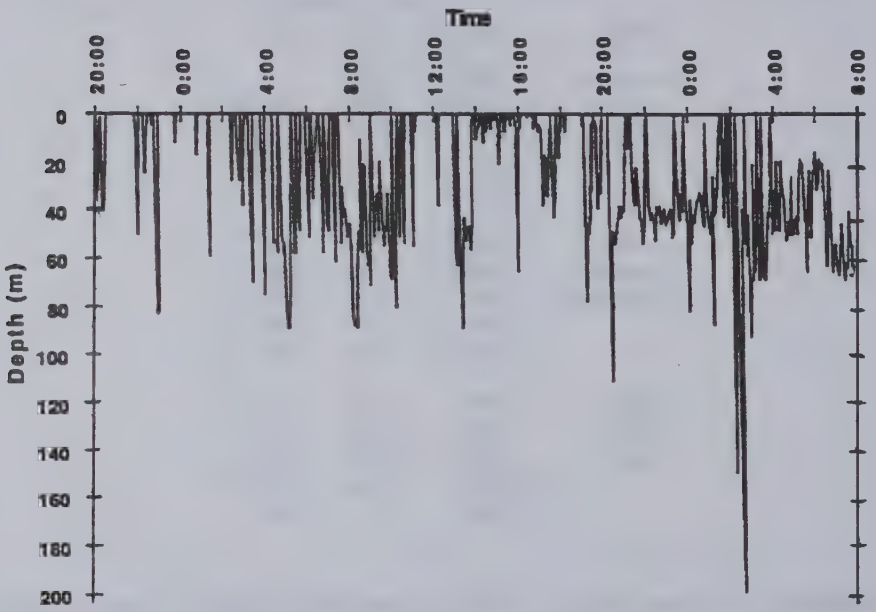

Figure 9. Depth distribution for 13 March 1994 for a juvenile SBT recorded by an archival tagged fish that had been at liberty for three months. The position of the fish was near but off the shelf of the Great Australian Bight.

Prior to the 1990s tagging experiment, there was little contact between CSIRO scientists conducting the tagging program and Japanese longline vessels. CSIRO scientists depended primarily on their contacts with Japanese SBT research scientists through the SBT assessment process for the promotion and recovery of tags. These Japanese scientists had no direct vested interest or involvement in the program and their work did not involve substantial direct contact with vessels and fishermen. Some promotional material was produced in Japanese but this did not occur until 1987 and there was not a good system for distribution of this material to the actual vessels. A further fact hindering recoveries was that the main location and time for reporting recoveries during the early years of the program was in Japan at the end of extended fishing campaigns. This meant that the time between the actual recoveries and the time when there was a chance for the information to be reported could be over one year. Under such circumstances, even if fishermen are well informed and have the intentions of reporting recoveries, it is all too easy just to forget or for the tags to get lost.

Promotion in the 1990s as discussed above has involved extensive direct contact with longline vessels as well as extensive preparation of tag recovery promotional material in Japanese followed by distribution of these materials directly to SBT longline fishing vessels. We believe that it is the combination of the following four factors that have made the main difference in the recovery rates: (1) the increased awareness of the program (e.g., a large fraction of the vessels now have tagging posters hung in their galleys), (2) visible and immediate provision of rewards, (3) the direct personal contacts and (4) the presence of observers on a significant fraction of vessels within the AFZ plus a small number of RTMP observers on the high sea. Thus, over 85% of the tag recoveries from longliners in the 1990s are the result of direct contact between the vessel and scientist, observers or tag liaison personal prior to the vessel returning to Japan. Only 12% of the tags have been recovered from vessels after they have returned to Japan.

It is impossible to estimate what fraction of the tags that were collected outside Japan would eventually have been recovered if they had not been returned prior to the vessel's return to Japan. However, some indication of the effectiveness of in-port vessel liaison visits can be ascertained from the tag recoveries off South Africa. In South Africa, the contract Japanese speaking liaison officers can only visit about 20-30% of the Japanese longliners fishing for SBT because of administrative reasons. Since these liaison personnel started visiting vessels, they have recovered 30 of the 60 tags recovered off South Africa which suggests that the recovery rate for vessels which are not visited in South Africa is only 25-40% of the rate for those which are visited. A further six of the 60 tags recovered from fishing operations off South Africa were reported during port visits in Australia or by Australian RTMP observers (see Table 19).

However, there are indications that reporting rates from Japanese longliners are less than 100% even in areas with high personal contact and extensive publicity. The SBT fishery off Tasmania receives the greatest publicity because of the location of the CSIRO laboratory on the docks in Hobart and the extensive use of Hobart as a port of call by Japanese longline vessels. All Japanese longline vessels fishing within the AFZ are required to have their holds inspected prior to and after the completion of fishing operations. Nearly 100% of the vessels are visited by CSIRO staff during these visits to Hobart and a large number of tags are reported in the process. The Tasmanian fishery has also had some of the most extensive observer coverage with over 30% of the vessels having an observer on board for part of their trips in 1991-93. Since observers are rotated among vessels while at sea, the overall observer coverage in terms of both fishing effort (i.e., number of hooks set) and number of SBT caught has been between 12 and 21% in 1991-93 (Table 20). Overall, around 27% of the reported tags that have been recovered from this fishery have occurred while observers are on-board. Observer coverage is spread throughout the season and fleet and is not targeted at any particular component and can be used to get an indication of reporting rates. The difference between the percentage of tags reported and the percentage of the catch/effort when observers are aboard vessels can be used to generate estimates of reporting rates. Such estimates for the Japanese and joint venture vessels fishing around Tasmania range from 37 to 80% and tend to be lower based on the coverage rate for effort than on the coverage rate for the number of SBT caught (Table 20). The reporting rate also appears to have increased in 1993 and may be some indication of the increased effectiveness of the promotional and recovery activities.

Table 19. The number of tags recovered from Japanese longline vessels by the various types of tag collectors. Note that this data has not been stored on the data base prior to 1993. Further note that the total number of Japanese recaptures in this table exceed the number in Table 10 since recovery from all releases are included and only surface releases from South and Western Australia in the later.

	Port Visit				In Japan		
Year	CSIRO Scientist	Japanese Speaking Contractor	Inspector	Observers	Industry	Scientist	Not Recorded
1993	92	37	5	58	1	24	6
1994*	60	28	6	51	2	19	0

*through November 1994.

Table 20. Estimates of the tag reporting rates in the Japanese longline fishery around Tasmania (140-155°E and 38-50°S) based on the number of tags recovered while AFZ observers were aboard vessels.

Year	Total number of recaptures	% of recaptures when observers aboard	% of SBT caught when observers aboard[1]	% of hooks when observers aboard	Estimated tag reporting rate	
					based on catch	based on hooks
1991	35	34	21	16	50%	37%
1992	76	24	12	12	43	42
1993	149	25	21	17	80	62

1) since observers only observe about 70% of hooks retrieved during a set, the number of SBT caught when observers were aboard was calculated as the product of the number of SBT observed caught times the ratio of the total number of hooks set while observers were on board times the total number of hooks observed.

The reporting rates in Table 20 for Japanese longliners also suggest that the reporting rate from the Australian domestic fleets may also not be 100% or else that a disproportional high number of tagged fish enter and or remain in the longline fishery off Tasmania. Thus, the estimated differential in the tag recovery rates between Australia and Japan longliners operating off Tasmania for most years and cohorts is not great enough if tagged fish are not disproportionally caught in the longline fishery off Tasmania. The movement/migration pattern of juvenile SBT could possibly result in disproportionally high recovery rates off Tasmania. Archival tagging and/or additional tagging from longline vessels off Tasmania could resolve this question.

The overall results from the current SBT tagging program emphasize the critical need for well developed and extensive tag recovery programs if results from large scale tagging programs are to be used to investigate and measure interactions between fisheries. Previous tuna tagging studies have resulted in very low longline recovery rates of tagged tuna relative to surface recoveries. The differential has been so great that researchers have been lead to suggest that the difference could not be attributed solely to differentials in reporting rates and that there was a biological, stock or behavioural component to the

difference. The comparison of the results from the 1983/84 and the 1990s tagging program clearly indicate that such a large differential in recovery rates can be due solely to differences in reporting rates. In cases where recovery rates are low, there is clearly a need to get verifiable estimates of the relative magnitude of different reporting rates if any qualitative, much less, quantitative inferences are to be made about potential interactions.

The need for estimating reporting rates has been recognised and recent work by the South Pacific Commission tagging program has demonstrated the need to get reasonable estimates from the large scale industrial surface tuna fisheries (SPC, 1994). In this case, most tags are discovered at the time of unloading and or processing, and tag seeding experiments by on-board observers provide a useful approach. For longline fisheries, designing experiments for measuring reporting rates is not a trivial matter. Since all fish are individually handled at the time of capture, tag seeding experiments are not a viable option. On board observers appear to be the only viable option at this point, but the logistic and financial implications are large for large scale observer programs in many longline fisheries.

In conclusion, the results from the current SBT tagging program indicate that low return rates from longline vessels should not be used as an indication of lack of interaction or lack of potential for interactions between surface and longline fisheries without a careful assessment on reporting rates. In the case of SBT, the current results indicate rapid and significant interchange of fish between the surface and sub-surface fishery. The results raise questions about previous suggestions/conclusions that the fish vulnerable to surface and longline gear constitute two distinct biological components and the lack of interaction between these two fisheries. However, at least in the cases of some yellowfin stocks, lack of interaction between these two fisheries is also supported by analyses of catch per unit effort and catch data (e.g., Fonteneau, 1988; SPC, 1994; Suzuki, 1994). In these cases, declines in catch rates by longliners and production model estimates of sustainable yields prior to the development of substantial surface fisheries are not consistent with subsequent catches taken in surface fisheries. As such the question of longline/surface interactions remains an open question for these species.

5. ACKNOWLEDGMENTS

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INTERACTIONS OF LONGTAIL TUNA FISHERIES IN THE WESTERN SOUTH CHINA SEA

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ABSTRACT

Longtail tuna (*Thunnus tonggol*) inhabit the coastal waters from the western Pacific Ocean to the northwestern Indian Ocean. The species mainly occurs in waters of northern Australia, East and South China Sea and North Indian Ocean (including the Red Sea and Gulf of Aden). In the South China Sea area, longtail tuna are found in abundance in the Gulf of Thailand and along the east coast of Peninsula Malaysia. Longtail tuna are caught by Thai purse seine and drift gillnet fisheries and by Malaysian purse seine, drift gillnet and hook-and-line fisheries. The total catch of longtail tuna from this general area has increased rapidly from 14,300 mt landed in 1980 to more than 100,000 mt in recent years; the increase has been the result of a dramatic increase in Thai purse seine landings. Presently about 90% of the longtail tuna catch is from the purse seine fisheries.

Intensive exploitation of longtail tuna by the purse seine fishery in the western part of the South China Sea (especially in the Gulf of Thailand) indicates a possible interaction between the purse seine fishery and other fisheries. This view is suggested by recent decreasing trends in CPUE in all of the other fisheries targeting longtail tuna in the area.

1. DISTRIBUTION AND CATCH OF LONGTAIL TUNA

Longtail tuna (*Thunnus tonggol*) is one of the typical neritic tuna species which inhabit the coastal waters from the western Pacific Ocean to the northwestern Indian Ocean including the Red Sea and Gulf of Aden (Fischer and Bianchi, 1994). Estimated catches of longtail tuna by FAO statistical areas are shown in Table 1. The annual total catch exceeded 150,000 mt in recent years. The central west Pacific Ocean (Area 71) which includes the South China Sea (Figure 1) recorded the bulk of the longtail tuna catch; the landings from this area exceeded 60% of the total catch.

The catches of longtail tuna in the South China Sea by country are shown in Table 2. The recorded catches include only those for Taiwan, Thailand and Malaysia fisheries. Considering the general continuity of distribution of a migratory species such as longtail tuna, it is suspected that the longtail tuna may not be reported properly in the catch statistics of some countries.

The western part of the South China Sea (Gulf of Thailand and coastal areas off East Peninsular Malaysia) has been known for its abundance of longtail tuna and this species is

Table 1. Catch of longtail tuna, by FAO Fishery Statistical Area, 1982-91.

Unit: 1,000 M/T

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
NW Indian Ocean (FAO 51) * (Iran, Oman, Pakistan) **	13.9	12.6	13.5	36.8	31.3	37.3	40.1	35.6	33	29.4
NE Indian Ocean (FAO 57) * (Thailand, Australia, India) **	7.1	6.7	6	2.5	2	1.5	1.4	1.5	1.1	1.1
CW Pacific Ocean (FAO 71) * (Thailand, Malaysia) **	16.5	50.5	39.2	46.4	47.1	38.2	92.5	82.3	104.9	115.3
NW Pacific Ocean (FAO 61) * (Taiwan) **	6.5	6.1	5.6	5.8	5.5	6.3	6.9	13.2	26.8	17.4
Total	44	75.8	64.4	91.5	85.9	83.2	140.9	132.7	165.8	163.2

* FAO Fishery Statistical Area
** Major Fishing Countries

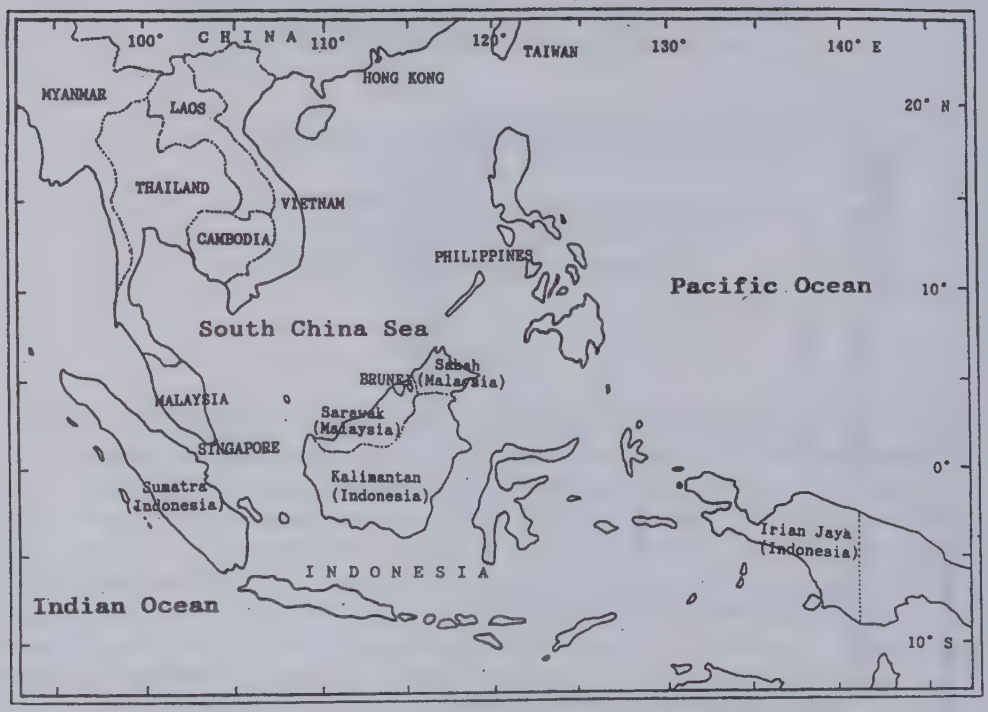

Figure 1. South China Sea.

one of the most important commercial species in this area. Although tagging experiments involving small tunas (kawakawa, *Euthynnus affinis*, and longtail tuna) have been carried out in waters of the east coast of Peninsular Malaysia since 1990, the recaptures of longtail tuna have not been sufficiently large enough to estimate movements and migration patterns (Raja Bidin, 1990). However, based on the relative differences in catch per unit effort (CPUE) of Thai fisheries and Malaysian fisheries in the area, the main concentration of longtail tuna appears to be in the Gulf of Thailand.

2. FISHERIES FOR LONGTAIL TUNA IN THE WESTERN SOUTH CHINA SEA

2.1 Thai Fisheries

The Thai fisheries operating in the Gulf of Thailand and connecting off-shore areas include the purse seine and drift gillnet fisheries. The longtail tuna caught by these fisheries comprise more than 99% of the total longtail tuna caught by Thai fisheries in this area.

Table 2. Catch of longtail tuna, by country, 1976-92.

Unit : Metric tons

	1976	1977	1978	1979	1980	1981	1982	1983	1984
Taiwan	74	420	253	208	179	259	366	323	
Philippines									
Hong Kong									
Kampuchea									
Vietnam									
Thailand				(12,503)	(8,671)	(11,564)	(23,416)	(53,805)	(44,374)
Gulf of Thai				10,583	7,962	9,958	16,306	50,449	38,556
Indian Ocean				1,920	709	1,606	7,110	3,356	5,822
Malaysia		(12,446)	(12,147)	(8,902)	(11,087)	(17,725)	(14,603)	(18,838)	(17,723)
West Peninsula		2,344	3,191	2,024	4,701	2,632	1,713	2,680	3,075
East Peninsula		10,102	8,956	6,878	6,386	15,093	12,890	16,158	14,648
Sabah									
Sarawak									
Singapore									
Brunei									
Indonesia									
Total	74	12,866	12,400	21,613	19,937	29,548	38,385	72,966	62,101

	1985	1986	1987	1988	1989	1990	1991	1992
Taiwan				7,290	5,876	5,754	3,624	
Philippines								
Hong Kong								
Kampuchea								
Vietnam								
Thailand	(48,000)	(48,299)	(65,911)	(92,925)	(82,125)	(102,436)	(84,847)	
Gulf of Thai	45,589	46,404	63,877	91,628	80,596	101,397	79,227	
Indian Ocean	2,411	1,895	2,034	1,297	1,529	1,039	5,620	
Malaysia	(19,151)	(16,590)	(25,484)	(26,641)	(17,123)	(17,812)	(28,058)	(35,003)
West Peninsula	4,551	4,036	6,719	5,035	3,666	4,626	5,051	8,194
East Peninsula	14,600	12,554	18,765	15,695	9,959	10,014	9,890	8,002
Sabah				5,101	1,986	721	11,124	16,698
Sarawak				810	1,512	2,451	1,993	2,109
Singapore								
Brunei								
Indonesia								
Total	67,151	64,889	91,395	126,856	105,124	126,002	116,529	35,003

Fishery Statistical Bulletin for South China Sea Area
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2.1.1 Thai purse seine fisheries

Until 1993, catch statistics of the Government of Thailand sub-categorized the purse seine fisheries into Thai purse seine, anchovy purse seine and luring purse seine fisheries. After 1994 the fisheries were categorized into only two types; the purse-seine and anchovy purse-seine fisheries.

The Thai purse seine operates in the daytime; fish schools are located visually and/or with the aid of sonar before the net is encircled around the school. The luring purse-seine uses electric lamps to attract fish schools at night or use fish shelters (payaos) which do the attracting of the schools (Okawara et al., 1986). The fisheries using these two types of purse seines usually target longtail tuna. The anchovy purse seine is made up of small-mesh netting and operates mostly in nearshore waters (Okawara et al., 1986). The catch of longtail tuna by the anchovy purse-seine is negligible.

Table 3 shows the number of purse seine vessels (Thai purse seine and luring purse seine vessels combined) by size of boat. About 650 purse seine boats are in operation annually; vessels make repeated fishing trips of 3-4 days duration. The most common size vessel is 20-100 tons and the average vessel is generally equipped with modern fishing gear. As shown in Table 4, the purse seine fishery catches a wide range of species. Although sardines, scads and Indo-Pacific mackerel were principal species landed in earlier years, the longtail tuna has become the first or second highest ranking species landed by the purse seine fishery in recent years.

2.1.2 Thai drift gillnet fisheries

The two types of drift gillnets are the Spanish mackerel gillnet (mesh size of 6-10 cm) and the mackerel encircling gillnet (mesh size of 4-4.5 cm). Both types of drift gillnets catch longtail tuna in this area; however, the longtail tuna catch by the mackerel encircling gillnet is a very minor component of the total catch (Okawara et al., 1986).

Table 3 shows the number of Spanish mackerel gillnet vessels by size; the majority of the vessels range in size from 10-50 tons. Approximately 250 of these gillnet vessels operate in the area with vessels making repeated fishing trips of 2-5 days duration. The catch by species of Spanish mackerel gillnet vessels is shown in Table 4; the longtail tuna accounts for about 30% of the catch.

2.2 Malaysian Fisheries

The three types of fishing gears operated by the Malaysian fisheries in waters off the east coast of Peninsular Malaysia include the purse seine, drift gillnet and hook-and-line. The longtail tuna caught by these three types of gear comprise more than 99% of the total longtail tuna catch in this area.

2.2.1 Malaysia purse seine fisheries

The purse seine fisheries of Malaysia can be classified into several groups according to methods of fishing and species targeted (Munprasit et al., 1989). The Statistical Bulletin

issued by the Government of Malaysia, however, lists only the purse-seine and anchovy purse-seine fisheries. The catch of longtail tuna by the anchovy purse seine is very small.

Table 3. Number of fishing units targeting longtail tuna, by country, gear type and size of vessel.

	Gear type	Size	1980	1985	1990
Thai Fisheries (Gulf of Thailand)	Purse Seine	< 10 (tons)	77	28	47
		10 - 20	131	69	45
		20 - 50	288	348	203
		50 - 100	111	206	287
		100 <	2	16	75
		Sub-total	609	667	657
	Drift Gillnet	< 10 (tons)	94	29	29
		10 - 20	107	82	51
		20 - 50	66	124	119
		50 - 100	5	20	34
		100 <			6
		Sub-total	272	256	239
Malaysia Fisheries (East Coast of Peninsula Malaysia)	Purse Seine	< 10 (tons)		1	2
		10 - 20		53	30
		20 - 50		72	73
		50 - 100		109	140
		100 <		6	3
		Sub-total	320	241	248
	Drift Gillnet	< 10 (tons)			
		10 - 20			
		20 - 50	Majority: 5-10 tons		
		50 - 100			
		100 <			
		Sub-total	1,487	879	1,053
	Hook & Line	< 10 (tons)			
		10 - 20			
		20 - 50	Majority: 5-15 tons		
		50 - 100			
		100 <			
		Sub-total	1,791	877	(1,300)

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There are about 240-320 one-boat purse seiners (including anchovy purse-seine vessels) operating in the area annually. The majority of these vessels are from 20 to 100 tons size (Table 3); fishing trips extend over 1 to 2 days.

The purse seiners usually operate at night using luring lights to attract fish; the principal species caught include scads, sardines and Indian mackerels. Longtail tuna are caught incidentally; thus, the longtail tuna catch from the Malaysia purse seine fishery makes up a substantially smaller fraction of the catch than the Thai purse seine fishery.

Table 4. Catch of major species by purse seine, drift gillnet and hook and line fisheries in the Western China Sea.

Unit : Metric tons

			1980	1985	1990
Purse Seine	Gulf of Thailand	Total	231,381	418,106	471,298
		Longtail Tuna	3,906	37,973	95,914
			(2%)	(9%)	(20%)
		Scads	53,719	47,202	40,651
		Jack, Trevallies	11,928	41,734	29,319
		Sardines	75,576	64,535	83,555
		Anchovies	1,914	14,827	432
		Eastern Longtail Tuna	2,319	22,785	49,468
		Indian Mackerel	17,104	29,775	15,718
		Indo-Pacific Mackerel	16,925	47,341	42,487
		Others	47,991	111,934	113,754
	East Coast Peninsula Malaysia	Total	50,487	59,381	78,183
		Longtail Tuna	890	2,961	3,671
			(2%)	(5%)	(5%)
		Scads	13,955	28,005	5,046
		Jack, Trevallies	393	131	264
		Sardines	6,572	4,678	8,383
		Anchovies	1,893		3,855
		Eastern Longtail Tuna			
		Indian Mackerel	19,331	20,819	8,488
		Indo-Pacific Mackerel			
		Others	7,453	2,787	48,476
Drift Gillnet	Gulf of Thailand	Total	11,505	25,172	15,595
		Longtail Tuna	3,108	7,327	4,919
			(27%)	(29%)	(32%)
		Jack, Trevallies	18	1	3
		Scads	245	69	54
		Black Pomfret	95	556	335
		Eastern Longtail Tuna	2,614	11,367	5,356
		Indian Mackerel		25	25
		Indo-Pacific Mackerel		19	17
		N-B King Mackerel	4,496	4,158	3,796
		Others	931	1,650	1,090
	East coast Peninsula Malaysia	Total	14,059	9,905	9,683
		Longtail Tuna	2,465	5,076	1,708
			(18%)	(51%)	(18%)
		Jack, Trevallies	61	45	408
		Scads	1,078	252	904
		Black Pomfret	355	58	69
		Eastern Longtail Tuna			
		Indian Mackerel	2,254	497	597
		Indo-Pacific Mackerel			
		N-B King Mackerel		1,613	
		Others	7,846	2,364	5,997
Hook & Line	East coast Peninsula Malaysia	Total	14,440	15,616	14,305
		Longtail Tuan	2,833	6,242	4,558
			(20%)	(40%)	(32%)
		Jack, Trevallies	223	425	363
		Scads	2,430	3,594	2,261
		Billfishes	579	146	85
		Indian Mackerel	480	772	138
		N-B King Mackerel	2,633	1,776	1,515
		Sharks	193	291	128
		Rays	173	129	155
		Others	4,896	2,241	5,102

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2.2.2 Malaysia drift gillnet fisheries

While there are several types of drift gillnets used in Malaysia, the Spanish mackerel gillnet (mesh size of 6.5 cm) is the most common gillnet used to catch longtail tuna; this is a similar situation as in Thailand.

Table 3 shows the number of vessels that use the Spanish mackerel gillnets; about 1,000 of these vessels operate in the area annually. The common size of vessel in this fishery is 5 to 10 tons. Fishing is carried out during the day and fishing trips are usually of one day duration. The catch by this fishery is shown in Table 4; longtail tuna make up a substantial part (18-51%) of the total catch.

2.2.3 Malaysia hook-and-line fisheries

The hook-and-line fisheries include handline, bottom longline and trolling. Longtail tuna are caught exclusively by troll lines and surface handlines. Data of the number of vessels fishing for longtail tuna are not available; however, the Malaysian Statistics lists more than 1,000 unclassified hook-and-line vessels. Most of these boats are 5-15 tons in size; fishing trips are from 5-6 days duration. The catch by these boats are shown in Table 4. The catch of longtail tuna comprises a substantial part (20-40%) of the total catch.

3. SIZE SELECTIVITY FOR LONGTAIL TUNA BY FISHERY

The size of longtail tuna caught differs according to the fishing gear used. Figure 2 shows the wide range of longtail tuna taken by the purse-seine fishery; fish range in size from 18 cm to over 50 cm. While the handline fishery also catches longtail tuna ranging in size from 15 cm to 50 cm, the majority of fish is from 25 cm to 40 cm. Since drift gillnets use a restricted net-mesh size, the range in size of longtail tuna caught by the drift-gillnet fishery is narrow; for 1989 the range was from 28 cm to 39 cm.

4. CATCH TRENDS OF LONGTAIL TUNA BY FISHERY

The total catch of longtail tuna from the area increased rapidly from about 10,000 mt in the late 1970s to more than 100,000 mt in recent years; a historical high in catch of 111,000 mt was landed in 1990 (Table 5 and Figure 3). In recent years the purse seine catch has accounted for nearly 90% of the total longtail tuna catch; the drift gillnet catch for 5-8% and the hook-and-line catch for 4-6%.

4.1 Purse Seine Fisheries

The combined catch of longtail tuna by the Thai and Malaysian purse-seine fisheries increased abruptly from several thousand tons landed annually prior to 1983 to 45,496 mt landed in 1983 (Table 5). Since 1983 the longtail tuna catch has shown a remarkable increasing trend, reaching a peak of more than 99,000 mt landed in 1990 (Table 5 and Figure 3). The dramatic increase has been primarily due to the increase in Thai catch; the Malaysian catch has remained at a relatively low level of less than 10,000 tons landed annually.

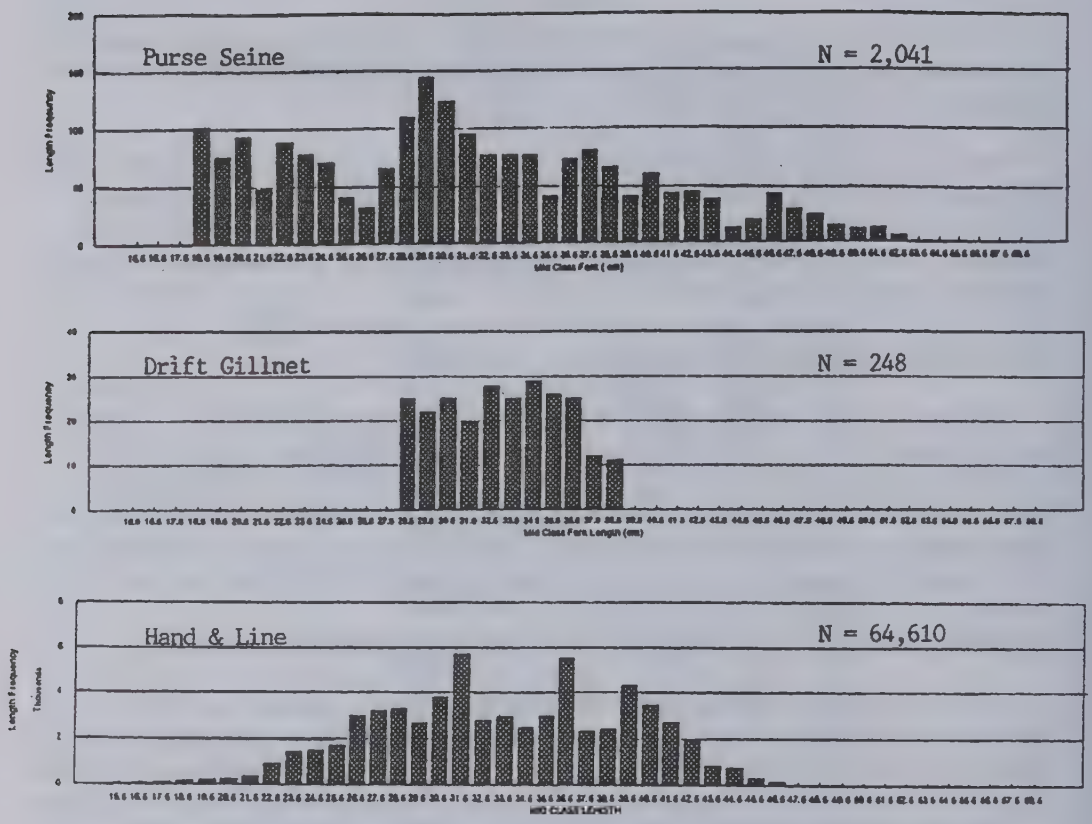

Figure 2. Length frequency distribution of longtail tuna caught by the Malaysian fishery, by gear type, in 1989 (sampling site: Kuala Terrenganu, Malaysia).

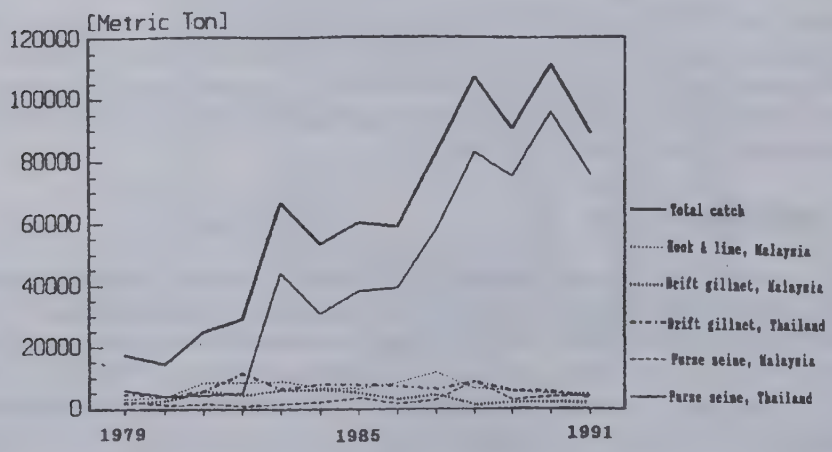

Figure 3. Catches of longtail tuna in the western part of the South China Sea,

Table 5. Catch of longtail tuna in the western South China Sea, by gear type, 1979-92.

Unit : Metric Tons

		1979	1980	1981	1982	1983	1984	1985
Purse Seine	Gulf of Thailand	5,811	3,906	4,102	4,841	44,017	30,628	38,022
	East P. Malaysia	1,936	890	1,330	490	1,479	2,045	3,275
	Sub-Total	7,747	4,796	5,432	5,331	45,496	32,673	41,297
Drift Gillnet	Gulf of Thailand	4,679	3,734	5,689	11,441	6,372	7,815	7,540
	East P. Malaysia	1,652	2,465	5,413	4,054	5,850	6,130	5,077
	Sub-Total	6,331	6,199	11,102	15,495	12,222	13,945	12,617
Hook & Line	East P. Malaysia	3,098	3,833	8,320	8,346	8,818	6,472	6,242
Other Gears	Gulf of Thailand	93	322	167	24	60	113	27
	East P. Malaysia	162	197	30		11	1	6
	Sub-Total	255	519	197	24	71	114	33
Grand-total		17,431	14,347	25,051	29,196	66,607	53,204	60,189

		1986	1987	1988	1989	1990	1991	1992
Purse Seine	Gulf of Thailand	39,131	57,721	82,929	75,199	95,914	75,802	
	East P. Malaysia	1,327	2,721	8,529	2,737	3,670	4,080	3,299
	Sub-Total	40,458	60,442	91,458	77,936	99,584	79,882	
Drift Gillnet	Gulf of Thailand	7,232	6,149	8,670	5,372	5,119	3,304	
	East P. Malaysia	2,842	4,303	872	1,848	1,708	1,297	1,091
	Sub-Total	10,074	10,452	9,542	7,220	6,827	4,601	
Hook & Line	East P. Malaysia	8,348	11,699	6,258	5,351	4,558	4,456	3,574
Other Gears	Gulf of Thailand	41	7	29	25	364	121	
	East P. Malaysia	37	42	36	23	78	57	37
	Sub-Total	78	49	65	48	442	178	
Grand-total		58,958	82,642	107,323	90,555	111,411	89,117	

The marked increase in the Thai purse seine catch has been attributed to increase in catch efficiency; the efficiency gained from the use of fish shelters (payaos), luring light and advanced electronic equipment, e.g., radar, sonar, echo-sounder and satellite navigation (Pramokchutima, 1992). The principal species caught by the Thai purse seiners has shifted gradually from round scads and sardine to Indo-Pacific mackerel, longtail tuna and kawakawa (Yanagawa, 1989; 1992). The shift in target species has been attributed to the increased demand by tuna canneries, especially for white meat tuna such as the longtail tuna. The tuna canneries developed in Thailand in the mid-1980s (Table 6) probably accelerated the targeting of longtail tuna by the Thai purse seiners.

4.2 Drift Gillnet Fisheries

The combined longtail tuna catch by the Thai and Malaysian drift-gillnet fisheries increased to more than 10,000 mt in the early 1980s; the peak catch of 15,500 mt occurred in 1982 (Table 5, Figure 3). Since 1982 the longtail tuna catch by drift gillnets has declined. It was noted that much of the decline in recent years has been due to the general acceptance of the United Nations Resolution of 1992, which called for a ban on large-scale drift gillnet fishing.

Although small-scale drift gillnet fisheries still operate in the western part of the South China Sea, some parts of Malaysia's EEZ waters in the area have become off-limits for fishing with gillnets; the restrictions were a means to protect marine turtles. The banning regulation went into effect in 1990. While banning of drift gillnets may have contributed to the low catches of longtail tuna by drift gillnets, other factors may be involved. It was noted that the declining trend in longtail tuna catches started earlier than the banning effort; the decline has been noted in the Thai drift gillnet fishery as well as the Malaysian drift gillnet fishery.

4.3 Hook-and-Line Fishery

The longtail tuna catch by the Malaysian hook-and-line fishery increased moderately up to 1987 when a catch of 11,700 mt was reported. However, since 1987 the longtail tuna catch has shown a decreasing trend (Table 5, Figure 3).

5. LONGTAIL TUNA CPUE BY FISHERY

The CPUE of longtail tuna by fishery are shown in Table 7 and Figure 4. The following sections describe the trends in CPUE by fishery.

5.1 Purse Seine Fisheries

The CPUE of longtail tuna by the Thai purse-seine fishery increased sharply in 1983 and continued to show a general increase until 1991 (Figure 4). The increase has been attributed to a shift in target species from scads and anchovy to longtail tuna and to improved fishing technology. The change in target species is shown by the sharp increase in longtail tuna as a percent of the total catch (Figure 5). Evidence that improved fishing technology is responsible for the increase in CPUE of longtail tuna is that the CPUE of other species also increased.

Table 6. Number of canning plants and quantity of tuna products, 1980-90.

Year	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
No of canning plants	-	14	24	26	38	39	41	41	45	43	42
Quantity (mt) of Little tuna	-	-	-	36,823	60,420	65,577	83,346	92,357	82,176	111,363	114,767
Tuna	-	-	-		85,700	106,325	191,418	195,246	274,911	331,953	
Total	-	-	-	36,823	146,120	171,902	274,764	287,603	357,087	443,316	

Somsak Pramokchutima (1992): Tuna Fishery Status: Thailand

Since the Malaysian purse seine fishery catches longtail tuna only incidentally, the longtail tuna CPUE for this fishery has been extremely low compared to the Thai fishery (Figure 4). Further, since 1988 the CPUE for the Malaysia fishery has shown a marked decline suggesting a possible decline in availability in the area fished by the Malaysian fleet. Whether this reflects the result of interaction needs to be explored.

5.2 Drift Gillnet Fisheries

Similar to the purse seine fisheries, the Thai and Malaysian drift-gillnet fisheries show a marked difference in CPUE (Table 7 and Figure 4). The reason for the difference may be due to differences in operational pattern or to factors such as differences in density of fish in the two fishing areas or differences in mesh-size used by the two fisheries. However, it is notable that a steady decline in the CPUE is observed for both fisheries in the late 1980s.

5.3 Malaysian Hook-and-Line Fishery

The CPUE of the Malaysian hook-and-line fishery increased moderately up to 1987; thereafter, the CPUE showed a steady decline (Table 7 and Figure 4).

6. POSSIBLE INTERACTION BETWEEN FISHERIES

Although some of the differences in CPUE between the Thai and Malaysian fisheries (purse seine and drift gillnet fisheries) may be due to differences in species targeted and in differences in fishing method and pattern, the large differences in CPUE levels cannot be explained very well without referring to other possible factors, e.g., differences in density or being the effects of interaction between the fisheries. If longtail tuna are concentrated in the Gulf of Thailand, an intensive effort by a highly mechanized fishery such as the purse seine fishery may have an effect upon the catch of other fisheries, especially if the resource is being exploited at a level that cannot be sustained. The exploitation rate of longtail tuna in Malaysian waters was estimated at 0.63, whereas the optimum exploitation rate was reported to be 0.49 (Raja Bidin and Rumpet, 1992). Considering the present high catch level of longtail tuna by the Thai purse seine fishery, over-exploitation of longtail tuna may have occurred in Thai waters, as well. The decreasing trends in CPUE of all of the other fisheries in the area in recent years indicate a possible effect of interaction between the purse seine fishery and the other fisheries.

7. DISCUSSION

Changes in the catch of longtail tuna in the western part of the South China Sea suggest that the Thai purse seine fishery may be affecting the other fisheries for longtail tuna in the area. To date, this view is only suggestive based on some catch and CPUE trends. Additional information is needed including evidence of longtail tuna movements in the area and basic population dynamics parameters, e.g., mortality and growth rates.

Presently SEAFDEC plans to aid in the improvement of collection systems for necessary fishery statistics. Plans are also being developed to undertake joint tagging programmes with countries fishing in the area. Finally, a modelling study of interaction among longtail tuna fisheries in the area is being considered for implementation.

Table 7. CPUE of longtail tuna in the western South China Sea, by gear type, 1979-91.

			1979	1980	1981	1982	1983	1984	1985
Purse Seine	Gulf of Thailand	Catch (ton)	5,811	3,906	4,102	4,811	43,916	30,455	37,973
		Fishing day	116,429	117,385	126,567	121,828	118,691	147,566	124,159
		Catch/Day	0.050	0.033	0.032	0.040	0.370	0.206	0.306
	East Coast Peninsula Malaysia	Catch (ton)		3,906	1,331	478	1,479	2,045	3,275
		Fishing day		117,385	58,590	47,341	44,318	48,878	47,458
		Catch/Day		0.033	0.023	0.01	0.033	0.042	0.069
Drift Gillnet	Gulf of Thailand	Catch (ton)	2,336	3,108	5,640	10,174	5,711	6,961	7,327
		Fishing day	39,926	35,515	44,478	40,302	47,253	47,457	44,862
		Catch/Day	0.059	0.088	0.127	0.252	0.121	0.147	0.163
	East Coast Peninsula Malaysia	Catch (ton)		2,645	5,413	4,054	5,850	6,130	5,077
		Fishing day		269,147	360,476	292,284	216,693	195,392	151,188
		Catch/Day		0.010	0.015	0.014	0.027	0.031	0.034
Hook & Line	East Coast Peninsula Malaysia	Catch (ton)		2,833	8,320	8,346	8,818	6,472	6,242
		Fishing day		385,065	412,828	304,560	223,745	193,620	187,897
		Catch/Day		0.007	0.02	0.027	0.039	0.033	0.033

			1986	1987	1988	1989	1990	1991
Purse Seine	Gulf of Thailand	Catch (ton)	39,131	57,721	82,929	75,188	95,914	75,764
		Fishing day	166,639	195,972	189,957	167,285	232,212	152,949
		Catch/Day	0.235	0.295	0.437	0.449	0.413	0.495
	East Coast Peninsula Malaysia	Catch (ton)	1,327	2,721	8,529	2,737	3,671	4,021
		Fishing day	37,736	43,245	42,051	45,586	58,034	565,632
		Catch/Day	0.035	0.063	0.203	0.06	0.063	0.007
Drift Gillnet	Gulf of Thailand	Catch (ton)	7,172	6,112	8,426	4,784	4,919	3,304
		Fishing day	56,609	57,485	76,915	46,571	60,377	36,078
		Catch/Day	0.127	0.106	0.11	0.103	0.081	0.092
	East Coast Peninsula Malaysia	Catch (ton)	2,842	4,303	872	1,848	1,708	1,297
		Fishing day	180,690	195,972	181,295	199,454	200,968	171,955
		Catch/Day	0.016	0.022	0.005	0.009	0.008	0.008
Hook & Line	East Coast Peninsula Malaysia	Catch (ton)	8,348	11,699	6,258	5,351	4,558	4,456
		Fishing day	135,180	169,187	183,160	260,210	308,455	240,622
		Catch/Day	0.062	0.069	0.034	0.021	0.015	0.019

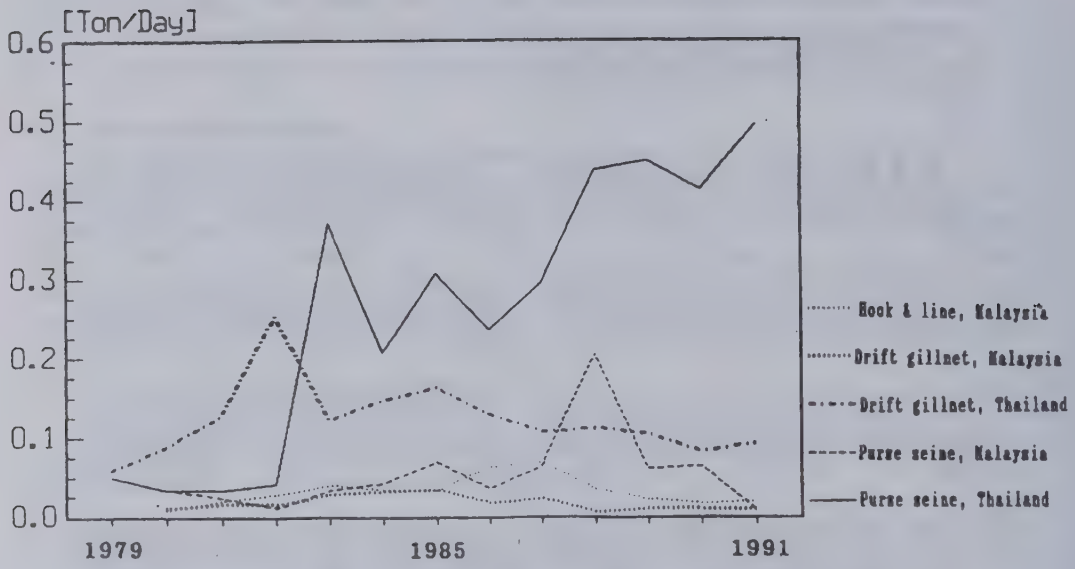

Figure 4. Longtail tuna CPUE trends in the western South China Sea, by gear type, 1979-91.

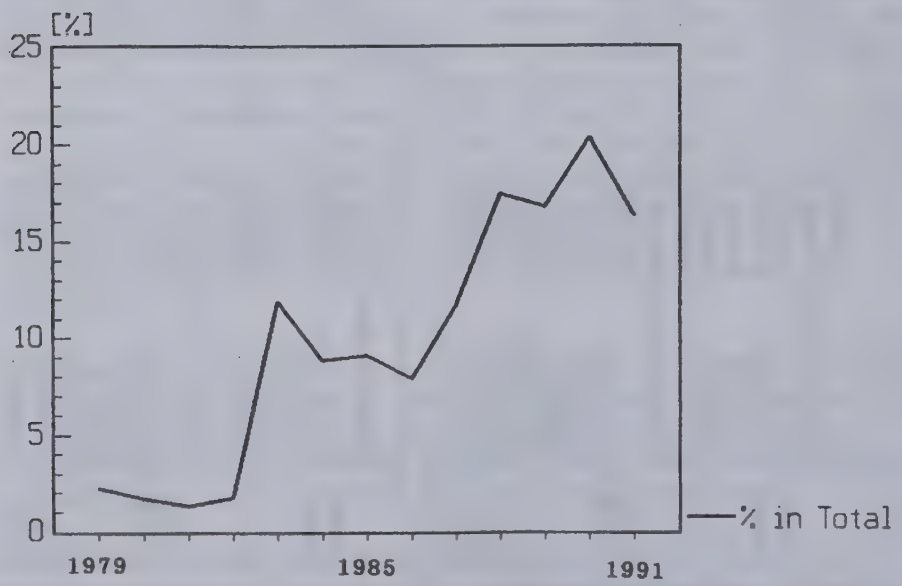

Figure 5. Change in proportion of longtail tuna in the total Thai purse seine catch, 1979-91.

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HUMAN INTERACTION IN TUNA FISHERY MANAGEMENT

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ABSTRACT

Research in fisheries management has usually focused on the dynamics of the fish resource, and issues relating to other aspects of management, have often played lesser roles. The First FAO Expert Consultation on Interactions of Pacific Tuna Fisheries held in Noumea, New Caledonia, in 1991 directed attention exclusively on resource-mediated interactions. While this decision avoided distractions from non-resource-mediated elements, it begged the issue of management. The present report reviews three examples of tuna interaction in the Pacific and notes the role that human interaction played in the management decisions related to these cases. The three case studies include the eastern Pacific tuna-dolphin, high seas drift gillnet, and pelagic fisheries in Hawaii. While these studies do not portray the entire spectrum of fisheries management, they demonstrate the critical role that human interplay has on fisheries management.

1. INTRODUCTION

In 1991 the Food and Agriculture Organization (FAO) of the United Nations organized a technical meeting to review tuna fisheries interaction in the Pacific Ocean (Shomura et al., 1994). In describing the features of tuna interaction, Kleiber (1994) classified fishery interactions as resource-mediated interactions and non-resource-mediated interactions. He noted that the focus of the 1991 consultation was on resource-mediated interactions and that the latter would not receive much attention. While this decision avoided straying from the important biological and fisheries aspects of tuna interaction, the absence of any discussion of human interactions in management of tuna fisheries may be an omission that should not be neglected since management decisions go beyond evaluating and weighing scientific

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evidence. Indeed, management decisions usually only begin with scientific evidence and are completed within a milieu of politics and emotion.

The present paper reviews briefly several tuna interaction cases in the Pacific and the resulting complex human interactions that led to specific management decisions. The case studies include (a) tuna-dolphin interaction in the eastern Pacific, (b) high seas drift gillnet fishery and the bycatch issue, and (c) pelagic fisheries interaction in the Hawaiian Islands area. It is not the intent of this paper to review in detail any of these issues, but to highlight events, the management decisions taken, and note the outcome of these decisions.

2. EASTERN PACIFIC TUNA-DOLPHIN PURSE SEINE FISHERY

The tuna-dolphin interaction in the eastern Pacific has resulted in dramatic changes in the purse seine fishery during the past two decades. Although the eastern Pacific purse seine fishery involved dolphins in their fishing operations since 1959, the problem of dolphin mortality did not come to public attention until 1968 (Perrin, 1968). Based on limited data, the mortality at that time was estimated at 350,000 dolphins per year (Joseph, 1994). The mortality drew the attention of conservation groups and the general public; the issue contributed greatly to the passage of the US Marine Mammal Protection Act (MMPA) of 1972 (Joseph, 1994). One goal of the MMPA was to have dolphin mortality reduced to insignificant levels approaching zero. The law, however, allowed for incidental kill of dolphins during the course of commercial fishing operations.

During years subsequent to passage of the MMPA there was a marked decline in dolphin mortality. The decline resulted from several efforts including establishment of an annual kill quota (which was reduced incrementally), gear requirements, elimination of sundown sets and the development of fishing procedures to allow escape of dolphins. By 1990 the dolphin mortality had been reduced to 53,000 animals (Joseph, 1994). Despite this marked reduction in mortality, the environmental community through public lobbying was able to make the tuna processing industry in the USA adopt a "dolphin-safe" policy. By virtue of this policy, adopted in 1990, the processing industry would only purchase tuna which carried a certification that it had not been caught in a porpoise-associated purse seine operation.

Subsequent events took two directions. In 1992, the international community working through the IATTC adopted an International Dolphin Conservation Program (IDCP). The objectives of the IDCP were to progressively reduce dolphin mortality to levels approaching zero and to seek means of capturing large yellowfin without the association of dolphins. This approach would ensure the continuation of a dolphin-associated purse-seine fishery. The other event was the passage by the US Congress of the International Dolphin Conservation Act of 1992 (IDCA). The Act called for a 5-year moratorium on dolphin-associated purse-seine fishing commencing 1 March 1994.

The two initiatives appear to head in diametrically opposite directions. The International Dolphin Conservation Program would continue to address the dolphin mortality problem while the dolphin-associated purse seine fishery continued. The current dolphin mortality rate attributed to purse seine operations has been estimated to be less than 0.1%, a mortality rate substantially lower than the dolphin replacement rate (2% to 6%) for

the various populations. Thus, the current bycatch rates of dolphin do not appear to endanger the overall populations levels.

The International Dolphin Conservation Act apparently will have little effect on the purse seine fishery of the USA since US-flag vessels have virtually quit operating in the eastern Pacific. Because embargoes are part of the IDCA, the Act will impact other nations that continue dolphin-associated purse seining. To date, the result of these actions has been (a) virtual collapse of US participation in the eastern Pacific tuna fishery, (b) consolidation of other tuna fleets in the eastern Pacific, especially Latin American countries, (c) development of markets other than USA for tuna taken from the eastern Pacific, (d) increase in consumption of tuna by Latin American countries, and (e) virtual elimination of the US as a market for eastern tropical Pacific tuna production.

The eastern Pacific dolphin issue appears to have taken a shift in objective and viewpoint as the mortality problem was being resolved. Initially, the prime concern and objective was to reduce the mortality of dolphin substantially and to assure maintenance of the dolphin populations at viable levels. As the mortality rates were reduced proponents of the "dolphin-safe" movement in the USA continued to push for zero-tolerance; thus, despite the success of the reduction in dolphin mortality, the USA purse seine fleet continued to be denied use of this fishing method in the eastern Pacific. Further, the continuance of the "dolphin-safe" policy appears to subject other nations with USA views relating to dolphins.

3. PELAGIC DRIFT GILLNET FISHERY

The demise of a newly-developed pelagic drift gillnet fishery in the 1970s provides a remarkable example of how perceptions and beliefs held by sectors outside the immediate fishery management structure are able to influence management decisions; decisions that are made before scientific evidence has justified a decision.

Until the 1970s, gillnets were mostly used in coastal waters and management problems were domestic in nature. An exception was the high-seas salmon fishery in the North Pacific, which reached its peak in the late 1950s. Management of this fishery was provided by the International North Pacific Fishery Commission (INPFC). When the fishery declined markedly due to the adoption of the 200-mile Exclusive Economic Zones in the North Pacific, especially by Japan and the USA, the problem of high seas competition for salmon was markedly reduced. That is, however, until the former salmon netters converted to catch squid. The squid fishery continued to catch large amounts of salmon on the high seas (Huppert and Mittleman, 1993). Huppert and Mittleman (1993) trace the conversion of salmon fishing vessels to fishing for neon flying squid, *Ommastrephes bartramii*, in the North Pacific. This newly developed fishery expanded rapidly in the 1970s with the addition of vessels converted from longline fishing (Gong et al., 1993). The gillnet fishery was not a single target fishery but one that ranged the Pacific and other oceans for marlins, swordfish, albacore, and other tunas (Gong et al., 1993; Huppert and Mittleman, 1993).

The magnitude of this pelagic gillnet fishery in the North Pacific and the movement by several distant water fishing nations to utilize pelagic gillnets for albacore in the Indian Ocean and the South Pacific were probably responsible for drawing an alarmed reaction by

South Pacific island nations (Cambell, 1989) and the world's environmental community. In a review of net fisheries in the North Pacific, Uchida (1985) noted that there were nearly 3.5 million units of nets available in the North Pacific which, if strung end to end, would extend a distance 4.2 times the earth's circumference at the equator. By the late 1980s articles began appearing in various publications deploring the actions of these "curtains of death" (e.g., see WPRFMC, 1990). Concern was directed mostly to the bycatch of these pelagic gillnets, especially marine mammals and seabirds. Additionally, concern in the USA was directed to the waste of resources (both target species and bycatch) due to "drop-outs" and to "ghost fishing" of derelict nets. It should be noted that all of these concerns were perceptions based on speculation or limited data.

In 1989 South Pacific island nations initiated formal objection procedures to stop a newly-developing pelagic gillnet fishery for albacore in the high latitudes of the South Pacific. Also, in late 1989 the UN General Assembly adopted Resolution No. 44/225, entitled "Large-Scale Pelagic Driftnet Fishing and its Impact on the Living Marine Resources of the World's Oceans and Seas" (Huppert and Mittleman, 1993). Among actions called for in the resolution was one to "..review of the best available scientific data on the impact of large-scale pelagic driftnet fishing by June 30, 1991...." A meeting was held in Tokyo, Japan from 4-6 November 1991 (Ito et al., 1993). Although limited bycatch data on pelagic gillnet fishery were provided in several of the technical papers of the meeting, there did not appear to be any quantitative measure of the impact of bycatch mortalities on the well-being of their respective populations.

In December 1991, the United Nations General Assembly adopted Resolution 46/215 on large-scale pelagic drift gillnet fishing which superseded resolution no. 44/225. Resolution 46/215 called for a 50% reduction in fishing effort by 30 June 1992, curtailed further expansion of high-seas gillnet fishing in other areas, and a global moratorium on all large-scale pelagic high seas drift gillnet fishing by 31 December 1992 (Huppert and Mittleman, 1993). Burke (1993), noted that prior to the adoption of Resolution 46/215 in December 1991, data of the South Korean and Taiwanese fleets for 1990 and 1991 were available. These data indicated the bycatch of these fleets were often "far below" rates experienced by other fisheries at that time. Also at the November 1991 meeting it was noted that observer programs specifically designed to collect detailed bycatch data from the gillnet fleets of Japan, Korea, and Taiwan fleets were started only in 1989 (Fitzgerald et al., 1993). Thus, the UN General Assembly decided to adopt resolution 46/215 in December 1991 even while data were just beginning to be gathered and analysed by the scientific community to determine the impact of bycatch by the pelagic gillnet fishery. The apparent basis for this decision was that it would be extremely difficult for driftnet nations to provide statistically sound evidence of "..the absence of harm to the marine environment and ecosystem of the North Pacific" (Huppert and Mittleman, 1993). It should be emphasized that under such criteria, very few fisheries would exist today. Similar views were expressed by Burke (1993).

It is unfortunate that policy makers did not allow for adequate evaluation of the high seas gillnet bycatch issue before advocating a ban of gillnet fishing in the high seas. In considering human emotions and prevailing views of resource utilization the rapid manner in which the gillnet issue was handled was not unexpected. On the one hand, the fishery landed large quantities of a resource that does not have wide-spread popularity and demand; thus, the supply-demand issue was not one of international dimensions. On the other hand,

available information indicated the gillnet bycatch to include seabirds, marine mammals, turtles and a wide range of fish species. This diverse bycatch resulted in convergence of wide-spread interest groups to oppose gillnet fishing. Interestingly, this appears to be one of the few instances when commercial fishing interests other than squid fishers, e.g. surface albacore fishery, were in concert with conservationists opposing gillnet fishing.

4. HAWAII'S PELAGIC FISHERIES

The case of Hawaii's pelagic fisheries interaction represents a situation where management decisions were made in the near absence of data that substantiated claims made by one pelagic fishery sector that another sector was having a direct impact on tuna resources and catches.

Hawaii's pelagic fisheries include a domestic longline fishery, a small pole-and-line fishery for skipjack tuna, commercial and recreational troll fisheries, and a coastal handline fishery for tunas. These fisheries have experienced the usual ups and downs in fishing success over the years (Boggs, 1994).

In the late 1980s, and coinciding with the "discovery" of productive swordfish grounds in the North Pacific and poor fishing in other areas, domestic longliners from the Atlantic and Gulf of Mexico moved to Hawaii in large numbers. The longline fleet increased from 35 vessels in 1987 to 135 in 1990 (Pooley, 1994). While longliners and other pelagic fishermen had existed peacefully in Hawaii for much of the 1900s, some of the new vessels set their gear in areas or in a manner different from those longliners that had been working in Hawaii for years.

In the early 1990s the conflicts between the new entrants in the longline fishery and the long-established commercial and recreational trollers in Hawaii increased beyond simple verbal complaints; cases of vandalism and even gunfire were reported (Pooley, 1990). The Western Pacific Regional Fishery Management Council (WPRFMC), as the principal federal management body in the region, examined available data. These data showed that with the exception of overlapping areas of fishing in some key locales, claims of reduced trolling success due to the expansion of the longline fleet could not be confirmed.

The WPRFMC held a series of public hearings to obtain views on the issue. Other than the instances of gear conflict, there did not appear to be sufficient evidence to promulgate management measures directed to resource impacts. While there was concern on the part of the council about the potential of localized overfishing and potential impacts on pelagic fish stocks, there were no data to support management actions based on these concerns. Some of the management measures were designed to halt the rapid expansion of the longline fishery, so that data on the fishery could be collected and analysed (e.g., federal logbook program and entry moratorium). The WPRFMC developed other measures that were justified largely on the basis of social aspects of the conflict (i.e., large areas closed to longline fishing around the main Hawaiian Islands. Skillman et al. (1993) reported that no research on longline-surface fishery gear conflicts had been carried out to support a management solution, and that the social and economic costs of the area closures were, and continue to be, borne almost entirely by one fishery sector, the longline fishery.

The lack of information defining the relative role and importance of the several pelagic fishery sectors in Hawaii led to management decisions which were based on the perceptions and vocal acclaim by the largest user group, the small-boat trolling sector.

5. CONCLUSION

While the dynamics of the fish stocks should perhaps be the foundation of management measures, fisheries management is fundamentally a process of human interaction and decision-making. The three examples summarized briefly in this paper point to management by public acclaim, a process which often ignores the quantity or quality of solid evidence about the resource. In the case of the eastern Pacific tuna-dolphin issue, the high dolphin mortality at the time of public exposure appears to have entrenched the views of the conservation groups and the general public in the USA to an immovable position. Although subsequent dolphin mortality was markedly reduced, and to levels far less than the dolphin replacement rates, the "dolphin-safe" movement appears to be holding fast for a zero-tolerance level.

The high seas gillnet issue suggests that even when available scientific evidence indicates the situation may not be as dire as presumed, public acclaim can even sway events at an international level. In this situation, it appears that separating the issue of coastal gillnet fishing from pelagic gillnet fishing eliminated the need to address bycatch problems of coastal gillnet fishing; gillnetting is a common method of fishing in coastal waters world-wide. On the other hand, the major pelagic gillnet fishing nations were few in numbers. The point made here is not that pelagic gillnet fishing is good or bad, or whether the level of bycatch is unconscionable, but that good management practice calls for review and evaluation of data leading to sound management decisions. This did not seem to be the case with the pelagic gillnet fishing issue.

The Hawaii pelagic fisheries conflict demonstrates the ability of one fishery sector to persuade managers to take a highly conservative position at the expense of another fishery sector. In Hawaii, with the exception of some overlap in the area of fishing, the available evidence did not demonstrate any impact of one fishery sector over the other that would have necessitated the management actions taken.

In summary, certain aspects of human interplay such as emotion and politics often overshadow science in the decision-making process for fisheries management. In contrast, the vast majority of funding and human resources, at least in the USA, are directed at assessment of the fish stocks and related topics. If fishery managers are to make rational, informed decisions, more attention must be focused on the human dimension of fisheries, such as sociology, cultural anthropology and economics. While having such information will not necessarily guarantee that good management decisions are made, fishery managers must have this information to consider all dimensions of the fishery and better avoid management by public acclaim.

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UNITED NATIONS CONFERENCE ON STRADDLING FISH STOCKS AND HIGHLY MIGRATORY FISH STOCKS:

Summary of Developments and Relevance to the FAO Consultation on Interaction of Pacific Tuna Fisheries

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ABSTRACT

The UN Conference has, to date, resulted in a draft agreement that is likely to have a significant impact on the way fisheries science is applied to straddling and highly migratory fish stocks. The draft agreement calls for conservation and management measures to ensure long-term sustainability and promote optimum utilization of straddling and highly migratory fish stocks, and, as such, it is clear that fishery interactions must be considered. The draft agreement also calls for biologically defensible means of ensuring that conservation and management measures are equivalent in promoting conservation; this also requires an understanding of how fisheries impact fish stocks and each other.

1. INTRODUCTION

There has been concern in the international community for some years regarding the impact on fish stocks of unregulated fishing on the high seas. While broad principals and measures regarding the conservation and management of fish stocks on the high seas are to be found in the 1982 United Nations Convention on the Law of the Sea (UNCLOS), it has been generally recognised that these broad principals and measures need to be more fully elaborated in order to be effective. Since 1990, a number of international meetings have been held for this purpose, including the International Conference on Conservation and Management of the Living Resources of High Seas, held at St. John's, Newfoundland in 1990, a meeting of Latin American States, Canada and New Zealand, held at Santiago, Chile, in May 1991 (which produced the "Santiago Document"), and the International Conference on Responsible Fishing Practices, held at Cancun, Mexico in May 1992.

Various initiatives developed at these meetings were pursued during the preparatory sessions of the United Nations Conference on Environment and Development (UNCED). Ultimately, UNCED agreed, in Agenda 21, that states should convene an inter-governmental conference under United Nations auspices with a view to promoting the effective implementation of the provisions of UNCLOS on straddling fish stocks and highly migratory fish stocks. The United Nations General Assembly resolution 47/192 (December 1992) subsequently called for the United Nations Conference on Straddling Fish Stocks and Highly Migratory Fish Stocks (hereafter referred to as the Conference) to be convened.

2. PROGRESS TO DATE

Three sessions of the Conference have now been held (July 1993, March 1994, August 1994) and a further two sessions are scheduled (March-April 1995, August 1995). Several inter-sessional meetings have also been held. Much of the work of the Conference to date had been directed towards the development and refinement of a Chairman's Negotiating Text, which took the form of a draft agreement among participating countries on measures that would essentially give effect to the provisions of UNCLOS regarding conservation and management measures for straddling and highly migratory fish stocks. At the August 1994 session, it was agreed that the outcome of the Conference would take the form of a legally-binding agreement. The Chairman's Negotiating Text was then re-drafted in treaty language and now takes the form of a "Draft Agreement for the Implementation of the Provisions of the United Nations Convention on the Law of the Sea of 10 December 1982 relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks." Copies of the current draft of the agreement (23 August 1994) are available from the Secretariat.

3. DRAFT AGREEMENT

While the wording of the draft agreement is subject to amendment during the final two sessions of the Conference, its basic structure and principals are likely to remain intact. The basic structure of the draft agreement is as follows:

PART I. General Provisions. Contains articles defining terms and scope and stating objectives and application of the agreement.

PART II. Conservation And Management Of Straddling Fish Stocks And Highly Migratory Fish Stocks. Contains articles outlining the obligations of coastal states and fishing states, the application of the precautionary approach and the requirement for compatibility of measures taken in EEZs and on the high seas.

PART III. Mechanisms For International Cooperation Concerning Straddling Fish Stocks And Highly Migratory Fish Stocks. Articles include obligations of states to cooperate, the role of regional organisations or arrangements, and participation of states in such organisations or arrangements.

PART IV. Responsibilities Of The Flag State.

PART V. Compliance And Enforcement.

PART VI. Port State Enforcement.

PART VII. Requirements Of Developing States.

PART VIII. Peaceful Settlement Of Disputes

PART IX. Non-participants.

PART X. Abuse Of Rights.

PART XI. Non-parties To This Agreement.

PART XII. Reports On Implementation And Review Conference.

PART XIII. Final Provisions.

ANNEX 1. Minimum Standard For Collection And Sharing Of Data.

ANNEX 2. Suggested Guidelines For Application Of Precautionary Reference Points In Conservation And Management Of Straddling Fish Stocks And Highly Migratory Fish Stocks.

ANNEX 3. Arbitration Procedure.

4. RELEVANCE TO FAO EXPERT CONSULTATION ON INTERACTIONS OF PACIFIC TUNA FISHERIES

The draft agreement has many references to technical issues and is likely to have a significant impact on the way fisheries science is applied to fish stocks covered by the agreement. Many of these issues are general, e.g., assessment of impacts on by-catch or ecologically related species, use of the precautionary approach, dealing with uncertainty in assessments and minimum data requirements for assessment. While such issues may be of interest to the Consultation, they go beyond our principal focus of fishery interaction.

However, there are two related areas of the draft agreement that can be pinpointed as being of direct relevance to our work. The first appears in Article 5 (a), in which it is stated that States shall "adopt conservation and management measures to ensure long-term sustainability and promote optimum utilization of straddling fish stocks and highly migratory fish stocks." For this obligation to be met, it is clear that fishery interaction must be accounted for. Most fisheries for straddling stocks and highly migratory stocks, almost by definition, comprise different interest groups that can be defined by nationality, fishing area, fishing method, or a combination of these. The impacts of each of these interest groups (or "fisheries") upon one another will need to be estimated in order to promote "optimum utilization." (The definition of what "optimum" really means and how different perspectives of "optimum" might be accommodated is yet to be elaborated.) The use of the term "optimum" also implies that socio-economic factors will need to be quantified and taken into account.

The second area which is of relevance to the work of this Consultation is elaborated in Article 7 of the draft agreement, which requires that compatible conservation and management measures be applied to straddling stocks and highly migratory stocks throughout their range. In particular, in determining compatible conservation and management measures, it is envisaged that States shall "take into account the biological unity and other characteristics of the stock(s) and the relationships between the distribution of the stock(s), the fisheries and the geographical particularities of the region, including the extent to which the stock(s) occur and are fished in areas under national jurisdiction" (Article 7-2(b)). The underlying intent of the article as a whole seems to be to ensure that

there is some biologically defensible means of ensuring that conservation and management measures on the high seas and in areas under national jurisdiction are somehow "equivalent" in effect in promoting conservation objectives. This requires an understanding of how fisheries operating in different area impact each other and the stock as a whole. Provision of scientific advice to fisheries management organisations or arrangements within these guidelines will present a substantial challenge to scientists. If it can be achieved, knowledge of the spatial variation in biological characteristics (recruitment, movement, mortality, growth, etc.) of the stock and spatial variation in fishing effort will be a prerequisite.

5. CONCLUSIONS

Future management requirements for straddling stocks and highly migratory stocks are likely to present new challenges to scientists. In order to meet these challenges, assessment methodologies will need to explicitly deal with spatial aspects of the stock and its exploitation as well as enabling interactions among the various interest groups involved to be quantified. Socio-economic factors are likely to be important components of these methodologies. The demands for data on the biological characteristics of the stocks and their fisheries to support such assessments will increase, and in particular, may need to be of greater spatial resolution than has been acceptable in the past.

EXAMINATION OF DATA RELEVANT TO TUNA FISHERIES INTERACTIONS IN THE PHILIPPINES AND INDONESIA

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ABSTRACT

The tuna fisheries in the Philippines and Indonesia represent a wide range of gear types including handliners, gillnets, baitboats and purse seiners. The present study was undertaken to determine if the data available from these fisheries were adequate to detect interactions between fisheries, and especially between the fisheries of Indonesia and Philippines. The results indicated that the data available from the tuna fisheries of Indonesia were inadequate, and that the data from the Philippines, while better, were not up-to-date. The conclusion was that the tuna fisheries systems in the two areas were so complex that catch and effort data alone would probably not be sufficient to model the system properly.

1. INTRODUCTION

A tour of the Philippines and Indonesia was made in November and December of 1993 to determine what data are available concerning tuna fisheries in the region. The purpose was to determine whether the data are sufficient to model the interactions between fisheries zones, and to make recommendations for improvement if the data are not sufficient. The primary interest was in the interactions between the fisheries of the two countries, so the northern part of Indonesia and the southern part of the Philippines were visited. Figure 1 gives shows the region concerned.

Tunas are taken in this region using a complex mixture of different methods, including handlines, gillnets, baitboats and purse seiners. Fish aggregation devices (FADs) are used extensively throughout the region by all types of vessels. The areas of operation overlap to a considerable extent, but are rarely completely coincident. The Philippines has the more complex mixture of gear types, but pole-and-line baitboats, which are common in

Indonesia, are rare or non-existent in the Philippines. In their place are many small purse seiners and ring netters; some such vessels also fish Indonesian waters.

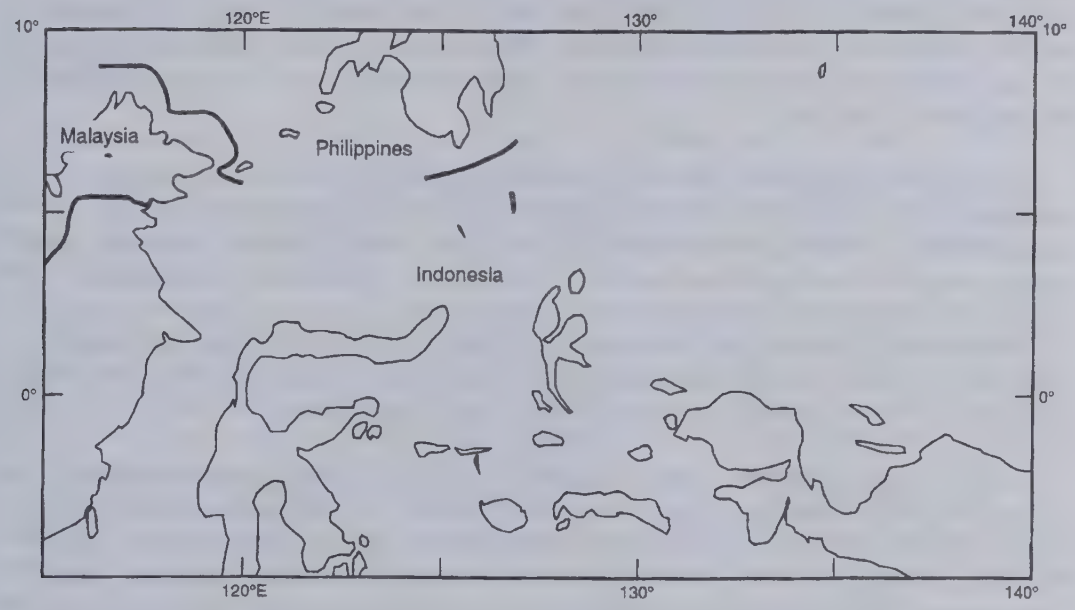

Figure 1. Map of the region concerned.

The small purse seiners and ring netters from the Philippines operating within the Exclusive Economic Zone (EEZ) present something of a quandary. They operate largely by agreement with the Indonesian government. Many of them land and process their catch in Indonesia and might be considered part of the Indonesian fishery. It was clear from our visit, however, that many Indonesians involved in the fishing industry are particularly concerned about what they perceive as competition from the Philippines. It seemed reasonable to consider these interactions, and other gear-type effects within a single EEZ, as intra-national rather than international interactions.

We concentrated on those interactions created when one fishery pre-empts another, that is, when one fishery reduces the exploitable fish population of another. This causes a reduction in catches of the second fishery, whatever the rate of exploitation in the second fishery. Other interactions also exist; some are direct, such as the independent use of FADs constructed and positioned by other boats. Others are less direct, such as the construction of canneries with a capacity greater than that of the local fleet. It was suggested to us that this might lead to a change in government policy. We have not attempted to evaluate this supposition, as that would be beyond the scope of this study. If such a policy change were envisaged, we would hope those concerned would consider the effects on the stocks of tuna. We therefore discuss whether the implications of such a hypothetical policy change might be anticipated.

Interactions of this type are determined by the abundance of each fish population and the rate of movement in both directions between them. Interactions are rarely symmetrical; that would require similarly sized populations and a balanced flow between them. There may also be some temporal distortion in the effects between fisheries. We can reasonably consider different gear types operating within the same region to be different fisheries if they have different age-specific selection profiles. In such cases it is likely that interaction will be asymmetric and temporally distorted. The gear that selects for older fish is likely to be more affected by the other gear than vice versa, and this effect will be delayed by the growth period of the fish.

Estimates of abundance could come either from an analysis of the estimated age structure of the catch, or from biomass models. Age-based analysis was pioneered independently by Murphy (1965), who named it cohort analysis, and Gulland (1965), who coined the term virtual population analysis (VPA). These methods require a sampling programme to determine the age structure within the catch. Generally, length frequencies are determined by measurement, and these are converted to age frequencies by means of a length-at-age table. Biomass models need much less detail concerning the catch, requiring only the total weight, but they additionally require estimates of effort.

Tagging experiments have been conducted in the region, but returns were still being made during this study and the analysis was not complete. Preliminary data from tagging studies show that skipjack move inside the Indonesian archipelago from the EEZ of the Philippines (Hampton, 1993). Given the dispersive nature of the fish's behaviour, it is likely that movements occur in the opposite direction. The interactions between fisheries of the two zones are determined by the rate of exchange in each direction, and by what that exchange represents as a fraction of the quantity of fish in each zone.

Neither yellowfin nor skipjack appears to perform *directed* migration; there is no clear consistent seasonal pattern to their movements. Their movement is characterized as dispersive, and the rate of dispersal is not consistent either. Mullen (1989) discussed these issues for yellowfin and argued that the variable rate of dispersal is a behavioural adaption that allows individuals to spend more time in better areas.

2. TUNA FISHERIES IN THE PHILIPPINES

The fisheries, and the data collection system created by the Philippines Bureau of Fisheries and Aquatic Resources (BFAR) in collaboration with the Indo-Pacific Tuna Management Programme, are detailed and extensive. The data are not complete, however, in the temporal sense. In December 1993 there was a two-year backlog of data, i.e., data for two years had not been entered into the system and provided to IPTP.

The data collection system has been described by Morón (1992). Employees of the BFAR routinely gather catch and effort data, and also measure samples of particular species taken from individual boats. All of the major ports and landing sites are sampled, but the large number of artisanal boats operating from beaches scattered all around the islands suggest that a significant proportion of the catch may go unmonitored.

The smallest vessels consist of hand-powered canoes which may be used to deploy bag nets, gillnets or handlines. Larger outrigger canoes are fitted with engines which

substantially increase their range. Larger vessels of approximately 15-25 tons are employed as purse seiners and ring netters. The largest vessels--the superseiners--exceed 1,000 tons (Aprieto, 1995).

The catch of bag nets and gillnets do not contain a high proportion of tunas, and will not be considered further in this paper. Superseiners will also not be considered further, as they tend to operate in distant waters. Hampton and Bailey (1993) discuss operations by superseiners.

There is some confusion as to nomenclature of purse seiners and ring netters. BFAR classifies any vessel with a power block as a purse seiner. Mr. Amadeo of Amadeo Fishing Co. explained, however, that for them the difference lies entirely in the design of the net. A ring net requires 30-60 men to haul, while a boat equipped with net and a power block would carry 25 men.

The difference between small purse seiners and ring-netters is perhaps moot. Both take fish swimming near the surface. Catches of skipjack and yellowfin are taken in similar proportions by both types of net, and the sizes of both species do not vary greatly between the two net types (see Morón, 1992). The handliners catch fish swimming deeper. Their catch is predominantly of large yellowfin (Figure 2) and bigeye tuna, while that of the surface fishery is of small yellowfin and skipjack (Figure 3). The fact that the largest yellowfin are not caught on the surface, but are taken at greater depths, is not unusual. For example, Nakano and Bayliff (1992) showed that, longlines, which fish deeper water than purse seiners, catch larger yellowfin than the purse seiners in the eastern Pacific.

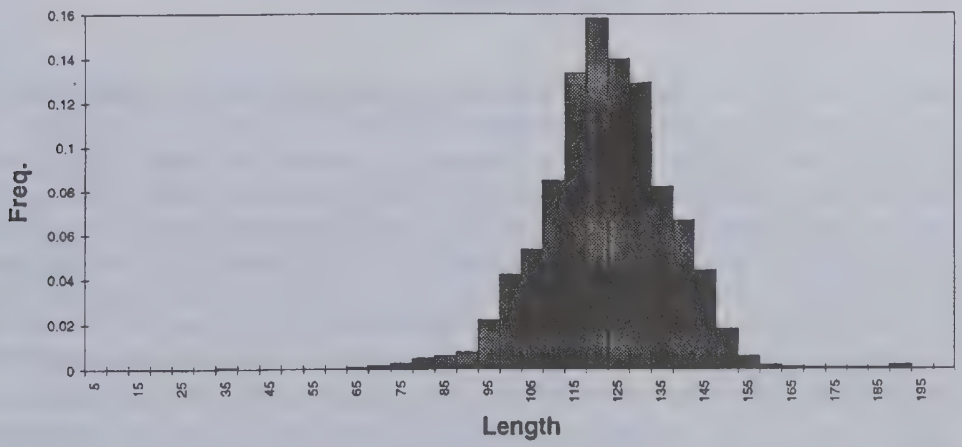

Figure 2. Relative frequency distribution for yellowfin caught at Lion Beach, General Santos, in 1991.

The preponderance of very small fish in the catches of purse seiners and ring netters shown in Figures 3 and 4 are, however, much greater than those taken by the superseiners in the eastern Pacific. Superseiners operating in the western Pacific, east of the Philippines, also take much larger fish than the surface fishery of the Philippines (Hampton and Bailey, 1993). The frequency of small fish sampled from the Philippines surface

fishery suggests fishing mortality might be very high. If so, the much larger yellowfin taken by handliners in the same area must be immigrants arriving as mature adults, rather than survivors of the surface fishery.

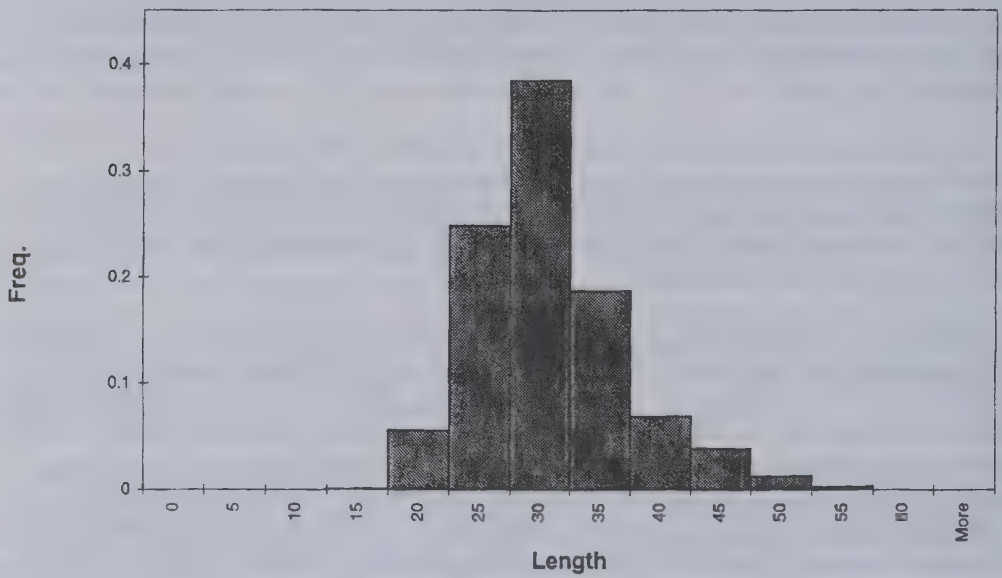

Figure 3. Relative frequency distribution for skipjack caught by purse seiners at General Santos in 1991.

There is, however, an alternative explanation. Small "light boats" are used to move fish from one FAD to another. They concentrate fish under a single FAD for a purse seiner or ring netter to make its set close to dawn. It is possible that larger fish are less attracted to the lights and are, thus, less susceptible to this form of fishing. The intermediate-sized fish may be able to evade the nets of the surface fishery. Purse seiners formerly working in the eastern Pacific were unable to fish successfully in the western Pacific until they had developed deeper, faster sinking nets that reached the thermocline, which is deeper in this region. Ring nets are approximately 300 m long and 30-60 m deep. We were told that a typical set takes approximately an hour. Larger fish swim faster and would be able to evade capture more easily.

It should be noted that Aprieto (1995) interprets the size intervals missing from the catch data as evidence for a life-cycle migration. This interpretation holds that yellowfin migrate out of the waters of the Philippines and return as much larger adults.

The data from 1980 presented by Morón (1992) show no consistent decline in catch rates except for Santa Cruz, and the size frequency of catches of yellowfin by purse seiners also appear stable. Again, this can be interpreted in two ways. The population exploited by purse seiners may already have been heavily overfished in 1980, and effort did not decline substantially, so the population has not recovered. Alternatively, the low catch

rates of the fish of intermediate size by the surface fishery may be due to the low vulnerability of those fish.

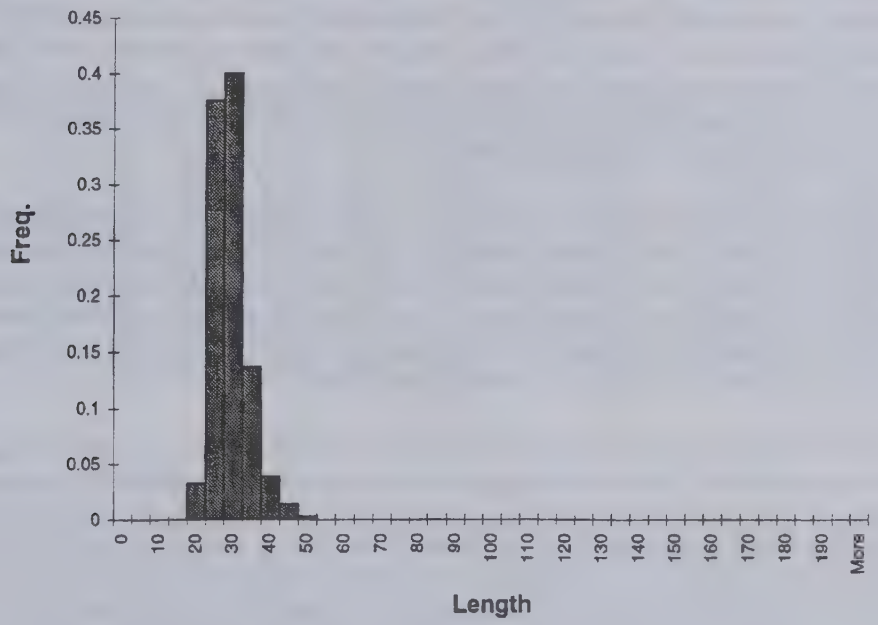

Figure 4. Relative frequency distribution for yellowfin caught by purse seiners at General Santos in 1991.

3. INDONESIAN TUNA FISHERIES

There are many strong contrasts between the fisheries of Indonesia and those of the Philippines. There is no database for Indonesia that is comparable with that of the Philippines. Data are available, but they are suspect for reasons discussed below. We were able to obtain potentially-useful data from commercial fishing companies. In this section we shall concentrate on the pole-and-line, or baitboat, fishery for skipjack.

To the casual observer, it seems there are fewer small landing sites in Indonesia compared to the Philippines, where fishing appears to be conducted from every conceivable point along the coast. In Indonesia, fish are seen as a resource which is not yet fully exploited, and the fishing industry is actively promoted by government as a growth industry. Except for vessels owned in the Philippines and operating within Indonesia's EEZ (but outside the archipelago), there are no purse seiners or ring netters. Nets are used for collecting bait for the pole-and-line fishery that operates here primarily for skipjack. As in the Philippines, yellowfin and bigeye are caught on handlines. In addition, a relatively small amount of these fish are caught on longlines and landed in Bitung. Catches of all these species are primarily for export. There is also some jigging for reef fish, as well as trolling for the local markets. Here, except for the zone where purse seiners and ring netters from the Philippines are permitted, the surface fishery is dominated by pole-and-line vessels.

An important part of the Indonesian government's approach for stimulating fisheries is the Nucleus Estate for Smallholders, or NES. The nucleus is a state-owned company and the smallholders consist of the owners of individual boats, as well as some who own several boats. The nucleus is in a position to direct activities of all the smallholders. It not only supplies bait and buys the catch of the smallholders, but also constructs FADs and places them in appropriate locations. These locations are based on several criteria--the availability of bait nearby, topography, and seasonal weather and oceanographic conditions. The Southern Monsoon makes fishing impossible from south-facing coasts, and catch rates are highest when operations can be resumed.

Social factors were also criteria in siting of at least one port. Mr. Rossu Hutubarat, director of P.T. Usaha Mina, explained to us in Labuha that the small local population had been part of the reason for expanding facilities there. Previously, Ternate had been an important fishing centre, and most of the boats operating out of Labuha are still based there. It was felt that much of the catch in Labuha was not landed to P.T. Usaha Mina, rather its was distributed directly to the local population.

The pivotal position of the nucleus enabled us to assess the validity of the existing data. It seemed that wherever there was the opportunity to compare data, there were serious discrepancies. For instance, the positions given as locations where catches had been made by baitboats seemed anomalous. We interviewed Mr. Abidin, the fishing operations manager for P.T. Usaha Mina, who told us that no boats associated with his company had ever fished where the catch was recorded as having occurred. These data were collected by workers in processing plant of P.T. Usaha Mina, and they were paid by RIMF for this extra work. In other cases, the total catch was not in concordance with the catch by size and species.

Itano (1993) describes the operations of the pole-and-line skipjack fishery. He also reports that the literature concludes that eastern Indonesia, as a whole, is not fully exploited, although some localities may be. The fishery seems to be limited by the availability of bait, rather than by the availability of tunas. Skipjack are the prime target of this fishery; the low fat content of skipjack in this region make them particularly suitable for the *katsuobushi* (dried fish) market, and they are exported to Japan. Some of the handline-caught yellowfin and bigeye is exported to Japan for sashimi. A preparation and packing plant has been constructed in Labuha to prepare sashimi ready for supermarkets. It is a joint venture with a Japanese company that had just started trial operations when we were there in November 1993.

The pivotal position of a single company in the pole-and-line fishery, P.T. Usaha Mina, compensates to some extent for the lack of reliable survey data. Their records were made freely available to us, and we were able to have extensive discussions with the officers of the company. The records kept by the company are of the form shown in Table 1. These data are likely to be accurate because they have been gathered for their commercial importance by those who intend to use them.

Table 1. Catch and effort of Sorong baitboat fishery, 1990. The table is for one class of baitboat, nominally 30 tons displacement. Columns are: M, month; Gear, 30 ton baitboats; OPD, operational days effort; bait consumed in "buckets"; kg of yellowfin, and skipjack by weight class (kg) of individuals, and the total catch of tunas.

MONTH	EFFORT	BAIT	YF<1.5	YF<2.5	YF<10	YF>10	SJ<1.0	SJ<2.5	SJ>2.5	TOTAL
1	282	16993	0	4715	48392	3663	80908	81669	173267	392614
2	343	20374		2248	37363	1792	74154	56764	399310	578070
3	408	23108	26486	6221	14221	26131	39445	67983	502674	706930
4	428	22383	15715	2676	20545	5236	76113	81701	410597	612583
5	494	30445	18119	15529	43289	827	206078	134998	390980	809820
6	422	24377	5538	6395	39077	151	46724	76531	289483	463099
7	528	26850	12370	14634	41978	1411	47342	68539	117446	303720
8	603	31566		6831	89184	8716	21690	30019	357468	513908
9	560	34470	5267	15187	138753	14465	44433	33689	437953	609747
10	652	39241	3080	3636	168457	6988	130292	102555	440187	855195
11	587	35674	7833	4960	117927	5295	58632	78764	428866	714026
12	514	34712	9850	28356	110910	4486	57328	117501	459906	788537

For the purposes of stock assessment, the information concerning the bait used may prove useful in revising the power of each unit of effort. The size categories used by the industry are too coarse to assess modal progression, but they are still useful. In Figures 5 and 6, it is possible to see that fewer large skipjack are caught around Sorong than at Fak Fak; they are separated by approximately 200 nm (see Figure 7).

Bitung, on the northeast coast of Sulawesi, is the main port for boats from the Philippines that land in Indonesia. There are several recently constructed canneries. The data that were made available to us by some of the canneries showed that the size distribution of the catch was similar to that found for catches made by similar boats in waters of the Philippines. Catches of the larger baitboats (up to 50 tons) in this region seem to be stable at present. It was reported to us that the smaller boats face difficulties catching bait on the north side of Sulawesi, which might be due to development that has occurred since the construction of a new road. Itano (1993) reports that pole-and-line fishermen of this region view as a resource the FADs placed by operators of purse seiners and ring netters. Mr. Rodriquez of RD Fishing in the Philippines told us however that their smaller purse seiners (they also operate superseiners) stay at least 50 miles from the Indonesian coast. This distance is maintained, he said, to minimise the interactions with Indonesian boats. Their licence entitles them to fish up to 12 nm from the coast.

4. DISCUSSION

It was stated that the data available for Indonesia were inadequate, and that those for the Philippines were much better although these were not up-to-date. In this section we discuss possible improvements that might be made to the data collection system, and the possible limitations of even a very good data set given the complexity of the system. Finally, we make suggestions given the information that are at our disposal.

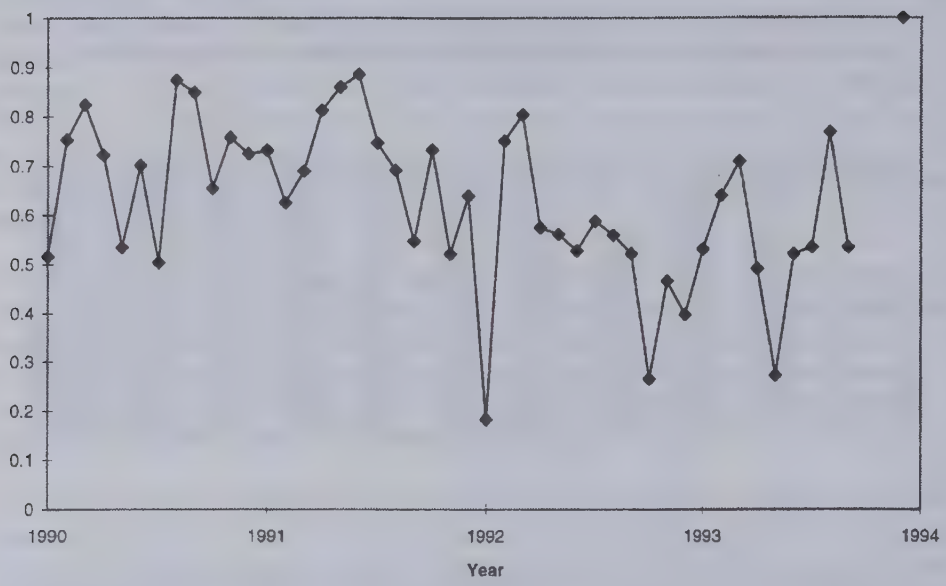

Figure 5. Proportion of skipjack in the largest size category that were caught in Sorong.

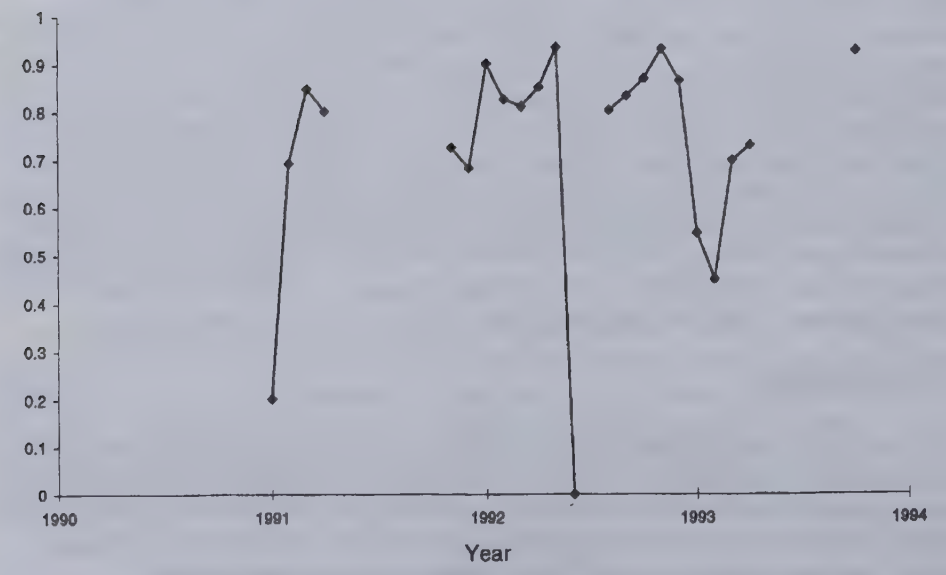

Figure 6. Proportion of skipjack in the largest size category that were caught in Fak Fak.

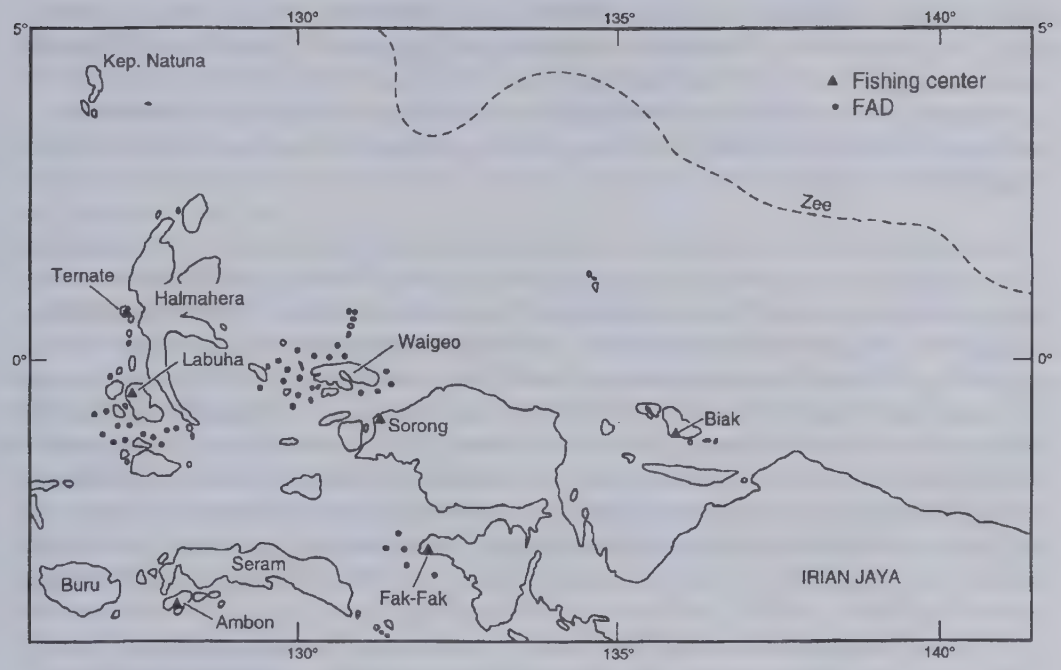

Figure 7. Map showing relative position of Sorong and Fak Fak in the northwest of Irian Jaya, and the locations of FADs.

The data from the Philippines should be transcribed from their raw form to computer files as quickly as practicable. This is not only so that they are available for analysis, but also so that apparent anomalies might be questioned while personnel are available and memories are fresh.

Currently, the boat captains are interviewed after trips and asked where they fished. If they operated outside the Philippines EEZ, this is a single category. Many of those boats will have been operating in the EEZ of Indonesia. Some land their catch in Indonesia, in which case the information should be gathered there. Others land in the Philippines, and it would be useful if all the data gathered for Philippine waters were also gathered from those boats that have worked in Indonesian waters. There may be problems in implementing this recommendation--the data are of more interest to the Indonesian government than to that of the Philippines, and some boats may have been fishing illegally. Gathering data concerning illegal fishing is often a problem, and one that might be overcome by some protection from self-incrimination. Such protection is believed to be effective, but we can offer no useful advice on this point.

It is hard to assess the impact of some of the smallest boats that use a variety of gear types and either consume their catch directly, or market it in ways that are difficult to monitor. An investigation would require a combination of careful anthropology, detailed sampling of the catch, and careful analysis of the statistics.

Other than the points noted, the data collection scheme in the Philippines provides a good model for Indonesia. That is not to say that the Philippines scheme can be copied easily. In a region where the samplers are necessarily dispersed, it must be hard to impart the attitude that the data are important, and much will depend upon the individuals that set up the system. Monitoring and questioning of unusual data might help, as would some feedback such as graphed time-series, etc. This is a difficult management problem, and we claim no special skill in that subject.

It should be noted that, even with complete and detailed information, this region would present a very difficult task for investigating interactions. The region is extremely complex in almost every aspect. The region is situated in a monsoon region. This, coupled with the very variable nature of the topography causes the oceanography of the region to be complex, both spatially and temporally. The weather associated with the monsoon imposes constraints on fishing operations, so strata without catches do not necessarily indicate few fish. Added to the physical and environmental constraints, are social issues. Market prices change and cause different size classes to be preferred by fishermen. Fleets in Indonesia are directed away from centres of population, while boats from the Philippines stay further than legally required from the coast of Indonesia. These problems are a general part of fisheries science, but we cannot think of another region that has them to the same degree.

A full assessment of interactions requires a complete spatio-temporal model of the region. Until relatively recently, fisheries models were spatially aggregated, which implicitly assumes a homogeneous distribution of both fish and fishing effort. If this is invalid then very poor estimates can result (Mullen, 1994). Spatio-temporal models exist for other regions, e.g., Mullen (1996) and Mullen et al. (1996). The spatio-temporal models described are for a much simpler region that is relatively well sampled, and are far from complete.

Boggs (1994) considered a more analogous problem, the fisheries of Hawaii. He considered a single pelagic population from which the fish of twelve localities were recruited, still an over-simplification for the fisheries considered here. Each local population in Boggs' model was subject to natural and fishing mortality upon immigration. The variation in fishing mortality caused local catch and catch per unit effort (CPUE) to vary through time differently. The pelagic population was considered constant at first, so every locality experienced constant immigration. In this case, he was able to establish relationships between the local CPUEs and catches. On relaxing the assumption of constant immigration by allowing it to decline by 40%, this relationship was weakened considerably. Boggs' conclusion from his simulation experiments was that catch and effort relationships might vary seasonally and annually. He goes on to say that CPUE versus effort should at least be useful in detecting the impact of local fishing on local CPUE, but that detecting the impact might require quantifying the effects of other factors.

Estimation of parameters is often a problem in fitting fisheries models to data. Models are frequently over-parameterised. Ludwig and Walters (1985, 1989) showed by simulation that, when used for management, simpler biomass models could sometimes out-perform more complex age-structured models that were known to be more realistic. This occurred when the data were uninformative and the parameters were obtained with little precision. The spatio-temporal model we envisage would make the age-structured model seem simple because it would also involve age-dependent movement parameters that might

be density dependent and/or vary through time. Clearly, such a model cannot be constructed now, and it might never be possible without exogenous determination of the movement parameters by, say, tagging experiments.

The work of Ludwig and Walters (1985, 1989) should be seen positively however. Simple models can give useful management advice. One of the first methods of analysis for fisheries was yield per recruit, and we propose to discuss the problem of interactions in this area using that idea.

Walters (1986) argues that strong signals imparted to natural systems can aid the analysis of that system. Such a signal may be imparted to the system soon, and this might be sufficient to ascertain the degree of interaction between the purse seiners and ring netters on one hand, and baitboats on the other. New canneries are planned for Bitung and Sorong, so the capacity of canneries is soon likely to exceed the catches of baitboats. There is speculation that, as a result, purse seiners and ring netters will be permitted to operate within the archipelago of Indonesia, where they are currently excluded. The experience of the Philippines suggests that the handliners may not be unduly affected by such a change. Indeed, yellowfin tuna may be grossly under-exploited in this region, although this may be part of the reason for the good catches in the Philippines. It is the baitboats that are likely to be affected, first and most. If so, then data of the sort shown in Table 1 would be sufficient to detect any substantial effect, but the magnitude of the effect cannot be predicted.

Clearly, the small fish taken by purse seiners and ring netters would lead to a low yield per recruit if most of the catch came from those boats. The important question is how large the overall populations of skipjack and yellowfin are within the archipelago of Indonesia. The current pole-and-line fishery gives little information because it concentrates on skipjack and is limited by bait, and the evidence of Figures 5 and 6 suggest the skipjack population is not uniformly distributed.

Unfortunately, changes in the catch rate of skipjack induced by enhanced mortality of young fish may have non-linear effect on the industry. The pole-and-line fishery is not economic at the current world price for skipjack, but it is profitable because the catch commands a higher price for *katsuobushi* (Hutubarat, P.T. Usaha Mina, pers. comm.).

In conclusion, we can say that the fisheries data alone are insufficient to assess the degree of interaction that exist between the two EEZs considered, or between surface netting and handlining for tunas. The system for gathering data could be improved, but there is no guarantee that even perfect catch and effort data would provide sufficient information for modelling such a complex system. There is no clear indication of a strong effect by purse seiners and ring netters on pole-and-line baitboats in the one zone where they now overlap. The low yield per recruit of the net fishery is a cause for serious concern, but the effects cannot be predicted until an estimate of the exploitable population is determined.

5. ACKNOWLEDGMENTS

We would like to thank all of the people from many fishing companies who freely gave us both their time and data. Mr. Zainal Abidin of P.T. Usaha Mina was especially

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SPECIES IDENTIFICATION OF SMALL JUVENILE TUNAS CAUGHT IN SURFACE FISHERIES IN THE PHILIPPINES

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ABSTRACT

The species identifications of small juvenile bigeye and yellowfin tunas, once made by field samplers working on tuna surface fisheries in the Philippines, were re-examined by mtDNA analysis. A total of 513 tunas between 150 and 400 mm fork length were collected and re-examined; 502 (97.9%) were analysed and eight (1.6 %) were misidentified. This indicates that species identification by samplers is, in general, accurate. The magnitude of the bigeye catch is likely to be much smaller than that of yellowfin, as indicated in the results of the sampling program.

1. INTRODUCTION

The Philippines tuna fisheries are characterized by a wide variety of artisanal fisheries and a large quantity of very small-sized tunas caught (200-300 mm fork length, FL). There is probably no other country catching such a significant amount of small tunas. Recent FAO catch statistics show nearly 80,000 mt of yellowfin tuna and 100,000 mt of skipjack tuna caught. Despite the fact that bigeye tuna are caught by the fisheries in the Philippines, no catch of bigeye has been reported in the FAO statistics or the Philippines national statistics, since bigeye catches are combined with those of yellowfin. This is probably reflecting the facts that the amount of bigeye catch is much smaller than yellowfin and there is no price difference paid at market for small fish of these two species.

To create more reliable catch and effort statistics and to facilitate tuna research, the Philippines Bureau of Fisheries and Aquatic Resources (BFAR), with the assistance of other international organizations such as South China Sea Fisheries Programme, Indo-Pacific Tuna Programme (IPTP) and South Pacific Commission (SPC), have conducted sampling surveys at several vessel off-loading sites in Philippines since 1979. While bigeye catches were reported in most of the sampling sites by some gears, e.g., purse seine and handline (Barüt and Arce, 1991; Morón, 1993; SPC, 1994), the estimated total catch for bigeye was not given.

The reliability of this sampling, however, is somewhat questionable because the catch of bigeye was not consistent, even in the same sampling site and by the same fishing gear,

while the catches of yellowfin and skipjack were relatively constant and at a high level. As it is known that skipjack, yellowfin and bigeye are caught together by the same fishing gear such as purse seine, a similar proportional catch is expected for bigeye. This inconsistency may be caused by species identification problem because yellowfin and bigeye tunas are morphologically very similar especially when they are young.

The main objective of this study is to check the accuracy of species identification in Philippines samples, especially between yellowfin and bigeye tunas, through genetic analyses and, if possible, to develop easy keys to separate these species based on the external characters. The results of this analysis can be very beneficial for the stock analysis of both tunas, since the catch in number could be quite large even if the catch in weight is relatively small.

2. FIELD SAMPLING

2.1 Methods

From April 1993 to February 1994, four field samplings were made in four major vessel off-loading sites in the Philippines. The first one took place in April and three more samplings were made in July, September and February. The sampling sites were General Santos in Mindanao (Celebes Sea), Puerto Princessa In Palawan (Sulu Sea), Masinloc in Luzon (South China Sea) and Atimonan in Luzon (Pacific). These locations are shown in Figure 1. These sampling sites were selected to consider the magnitude and modes of fishing operations, and to cover as wide an area as possible.

The sampling scheme was to collect yellowfin and bigeye tunas of 150-350 mm FL, randomly selecting five fish in every 50 mm length interval, at each sampling site and time. Accordingly, the total number of fish sampled would be 320 fishes for each sampling. In this way, it was expected that there would be enough fish to estimate the ratio of species misidentifications by samplers, if it existed. In addition, the sample should be large enough to characterise any changes in morphological characters by size and by season.

Field identification of tuna species was mostly made by the field samplers hired by BFAR in the same manner as they do in the normal sampling, except in Atimonan where the authors made species identification. All the sampling was accompanied by N. Barüt. N. Miyabe and S. Chow joined the first and the third sampling, respectively. These samplers and authors who participated in the sampling spent several days at each sampling site waiting for the off-loading of small tunas. Most of small tunas came from ring nets, purse seines and handlining. After each fish was identified, the fork length and body weight were measured with calipers and a scale, respectively, and a small amount of tissue sample (a few grams) was taken. The fish and tissue samples were preserved in formalin and ethanol, respectively, within few hours after the sampling and later transported to the National Research Institute for Far Seas Fisheries (NRIFSF) in Shimizu. Samples in formalin were further sent to I. Nakamura, Kyoto University, for subsequent morphological analysis.

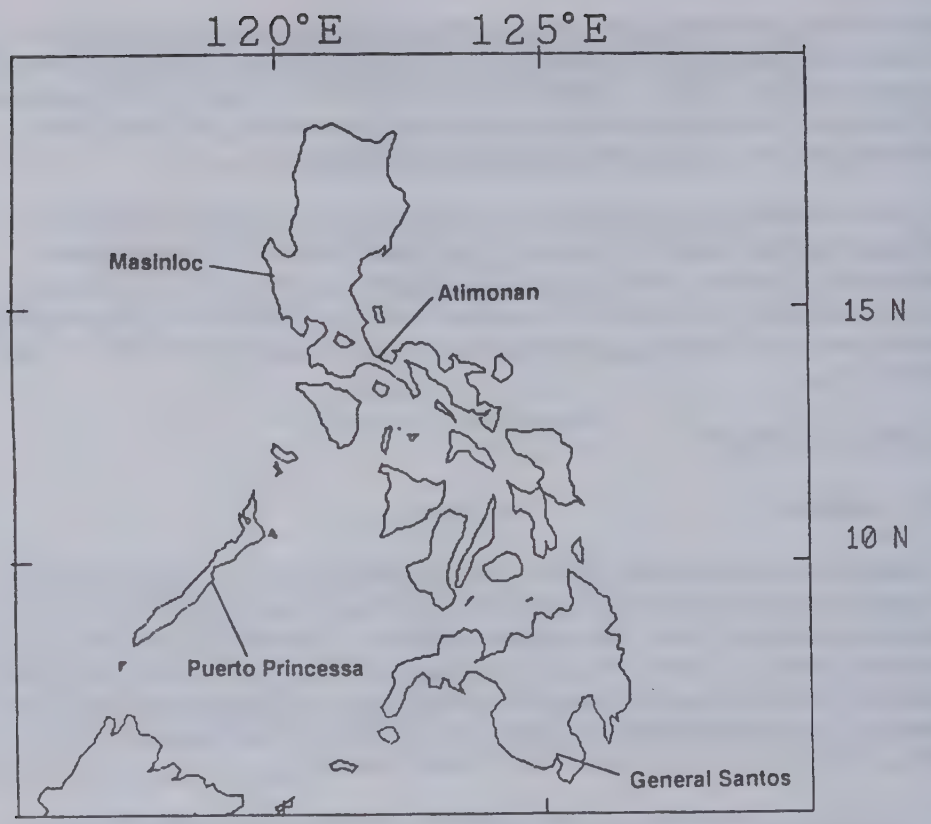

Figure 1. Areas of juvenile tuna sampling in Philippines.

2.2 Results of Data Collection

A total of 513 tunas were collected and identified based on external characteristics--395 yellowfin and 118 bigeye. This is only about 40% of the expected sample size. Table 1 shows the number of fish by sampling location and species. The only site where sampling was done satisfactorily was General Santos. At Masinloc and Atimonan, complete sampling was not successful except for yellowfin at the third sampling. The sampling of yellowfin was almost complete in Puerto Princessa, but not enough bigeye were sampled as scheduled.

There are several reasons for the incomplete sampling. One is that the duration of the sampling period was not long enough. Occasionally, landings of small tunas were made a few days before we arrived. Another reason is that fishing operations by ring net or small-scale purse seine, which catch small tunas in substantial quantities, was seasonal, and no operations were conducted during the sampling periods. This is true, in part, at Atimonan, where purse seiners and ring netters operate seasonally.

Table 1. Number of fish collected by field sampling in Philippines. Figures in bracket show the number of misidentified fish.

	1st Sampling		2nd Sampling		3rd Sampling		4th Sampling	
Period	14-19 Apr		24 Jul - 2 Aug		21 Sep - 31 Oct		8 Jan - 4 Feb	
Place / Species	YFT	BET	YFT	BET	YFT	BET	YFT	BET
General Santos	36	36	54	47	46	18	42	8
Puerto Princessa	12*	0	42	4	40(2)	0	26(1)	0
Masinloc	0	0	0	0	32(1)**	5(3)	5(1)	0
Atimonan	0	0	0	0	60	0	0	0
Total	48	36	96	51	178	23	73	8

YFT total = 395, BET total = 118, Grand total = 513
Numbers used for mtDNA (YFT=384, BET=118, total=502)
* 2 yellowfin failed to be amplified mtDNA
** 9 yellowfin failed to be amplified mtDNA

The length frequency distributions of sampled fish are shown in Figures 2-6, by sampling site and season. Fish smaller than 200 mm FL are relatively scarce. Reflecting the sampling scheme, samples are scattered more or less evenly between 200 and 400 mm. When the desired sampling scheme could not be met due to shortage of tuna catch or absence of required fish size, fish from other length classes were sampled to reach the expected sample number, and in some cases larger-sized fish up to 400 mm were included.

Species identification using external characters such as marks and bands (Figure 7) on the lateral part of body, the diameter of eye orbit, length of pectoral fin and body depth seems relatively easy for a well-trained sampler when fish are fresh, but it is difficult to separate bigeye from yellowfin when those characters are not clear after storage on ice or when the fish is damaged. Skipjack tuna is simple to identify because it has clear banding on the side of the body and a rather elongated body. Bigeye and yellowfin are easily separated from skipjack, for fish bigger than 200 mm, since the former have elongated pectoral fins.

Unfortunately, for small tunas, the morphological analysis of yellowfin and bigeye to develop easy keys for the species identification has not been completed. The results will be reported soon after the analysis is completed.

3. SPECIES IDENTIFICATION USING mtDNA

Once morphologically identified and sampled, bigeye and yellowfin tunas were re-examined by mitochondrial DNA (mtDNA) analysis. The procedure for DNA extraction, optimal condition for amplifying mitochondrial ATPase gene, and the diagnostic restriction profiles between species of *Thunnus* are described in Chow et al. (1993) and Chow and Inoue (1993). Since bigeye tuna has been reported to represent distinct restriction profiles from the yellowfin tuna by the restriction endonucleases *Mse* I and *Rsa* I, one of these restriction endonucleases were used in this study. Representative differences in the restriction profiles between the yellowfin and bigeye tunas are shown in Figures 8 and 9. Mitochondrial ATPase gene fragments of 384 individuals of designated yellowfin tuna were successfully amplified, and the restriction analysis indicated five specimens to have bigeye-

type mtDNA. All 118 designated bigeye tuna were successfully amplified, of which three possessed yellowfin-type mtDNA (Table 1).

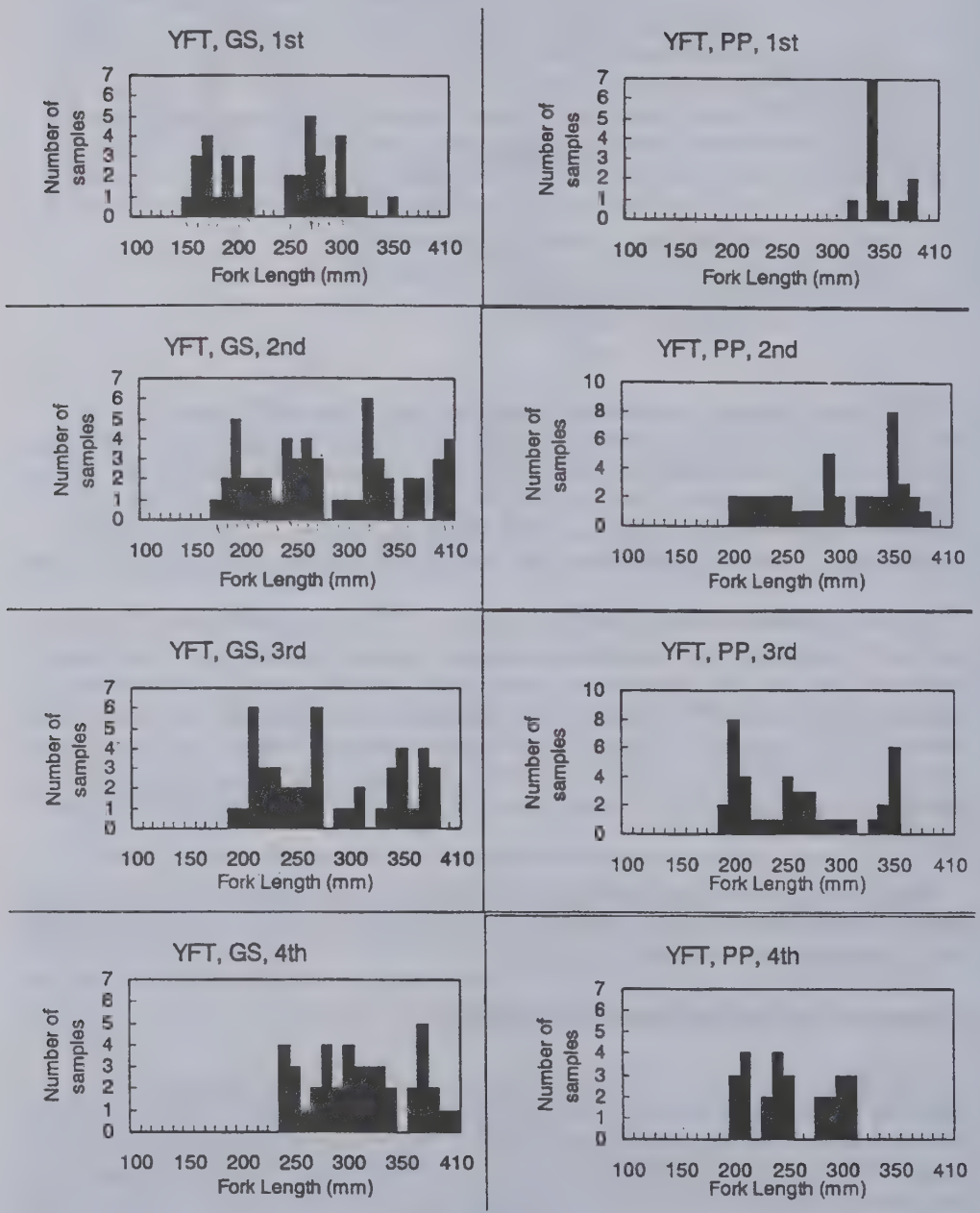

Figure 2. Length frequency of sampled yellowfin in General Santos (GS) and Puerto Princessa (PP).

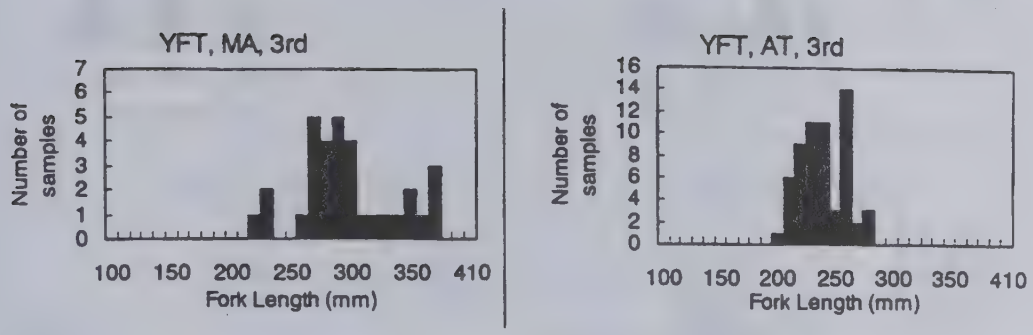
YFT, MA, 3rd
Number of samples
0 1 2 3 4 5 6 7
100 150 200 250 300 350 410
Fork Length (mm)
YFT, AT, 3rd
Number of samples
0 2 4 6 8 10 12 14 16
100 150 200 250 300 350 410
Fork Length (mm)

Figure 3. Length frequency of sampled yellowfin in Masinloc (MA) and Atimonan (AT).

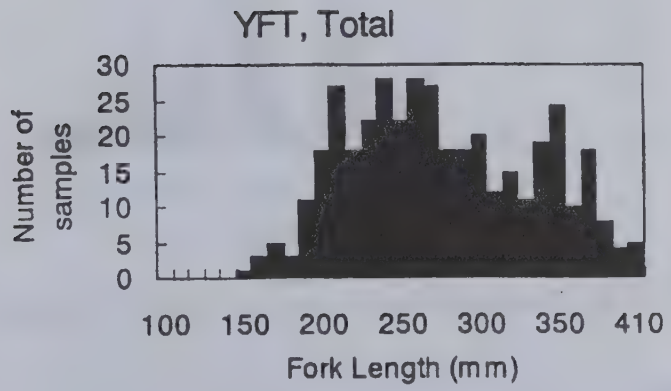

Figure 4. Total length frequency of sampled yellowfin in Philippines.

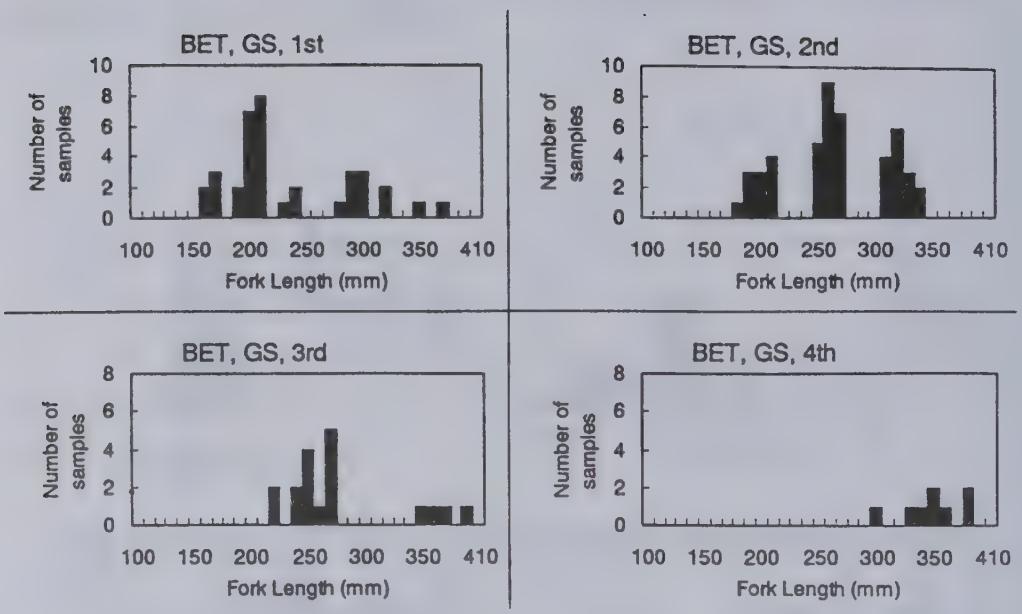

Figure 5. Length frequency of sampled bigeye in General Santos (GS).

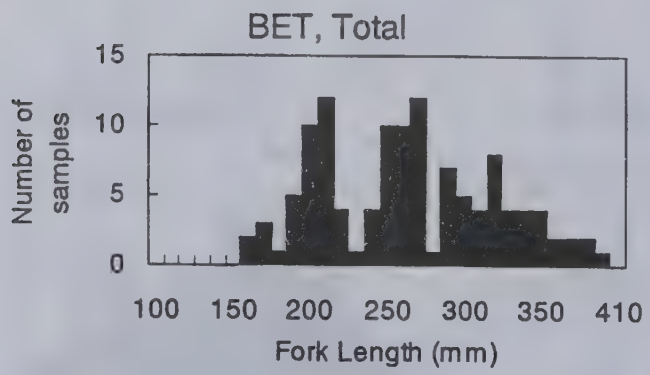

Figure 6. Total length frequency of sampled bigeye in Philippines.

4. DISCUSSION

According to the mtDNA analysis, eight (1.6 %) of 502 tunas were misidentified. Five (1.3 %) were misidentified as yellowfin and three (2.5 %) as bigeye. It is interesting to note that wrong identifications were observed in only two sampling sites when the sample size was incomplete. The misidentification rate for the two species combined was 2.5% in

Puerto Princessa and 12.1% in Masinloc. This may indicate that samplers in those places were less experienced. Nonetheless, the results of mtDNA analysis indicate that species identification by samplers is generally accurate and usable. As indicated in the results of sampling program, the magnitude of bigeye catch is likely to be much smaller than that of yellowfin.

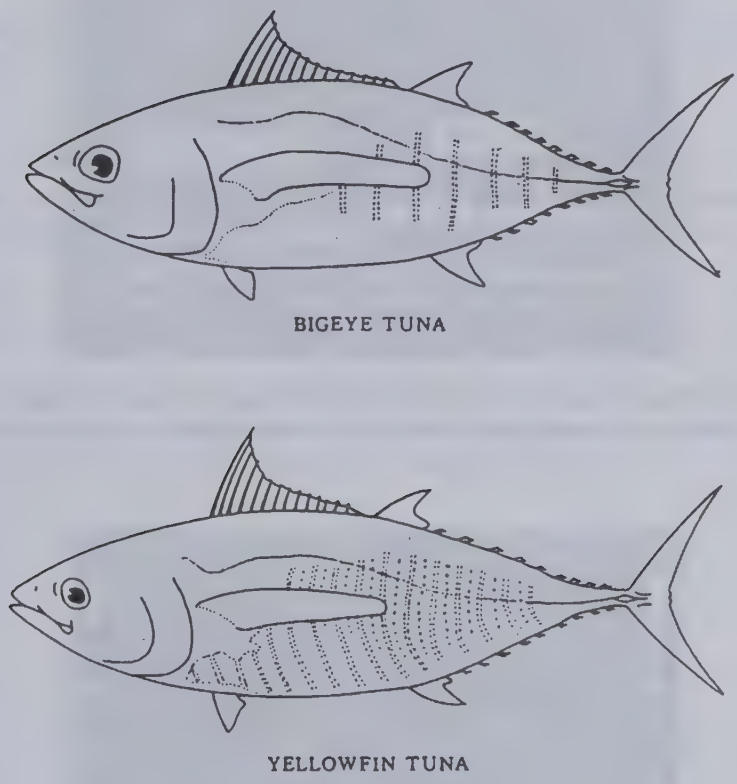

Figure 7. Lateral marks and bands of bigeye and yellowfin tunas (after Honma et al., 1973).

Figure 8. Restriction profile of mitochondrial ATPase gene fragments digested by *Mse* I endonuclease, showing clear differences between yellowfin and bigeye tunas.

Figure 9. Restriction profile of mitochondrial ATPase gene fragments digested by *Rsa* I endonuclease, showing clear differences between yellowfin and bigeye tunas.

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OVERVIEW OF THE BIOLOGICAL, ECONOMIC, SOCIAL AND POLITICAL CONCERNS RELATED TO INTERACTIONS OF PACIFIC TUNA FISHERIES

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ABSTRACT

The types of tuna interaction problems and their relevance to the central and western Pacific Ocean were considered in some detail in several papers presented at the First FAO Expert Consultation on Interactions of Pacific Tuna Fisheries, held in Noumea, New Caledonia, in 1991. This paper provides further information on the types of interaction problems that Forum Fisheries Agency (FFA) member countries are experiencing in regard to the management of their tuna fisheries. The implications of these problems and the measures that the countries are taking to address them are also considered. The paper is focused on the economic and social aspects of the problem.

1. INTRODUCTION

The sustainable harvesting of the region's tuna resources is fundamental to the future economic health of the island countries of the Forum Fisheries Agency (FFA)[1]. In 1994, FFA countries received around US$60 million in fees under various bilateral and multilateral arrangements with distant water fishing interests in exchange for fisheries access to the FFA countries' respective Exclusive Economic Zones (EEZs). The level of access fees is substantial in relation to the general size of the economies of the island countries. In many countries, the revenue received from the licensing of foreign vessels represents the largest source of recurrent government revenue.

Recent studies by the World Bank have estimated that the real gross national product of the Pacific Island countries grew by an average rate of 0.1% per year in the past decade. Although there are difficulties in measuring accurate economic indicators given the extent of the non-cash economy in most Pacific Island countries, the result nevertheless indicate a generally sluggish level of economic growth in the region.

The economic development of the island countries of the Pacific region must contend with a number of significant natural barriers including geographic isolation, limited population base, small domestic markets, limited supply of natural resources and vulnerability to natural disasters. In June 1994, the Australian Minister for Development Cooperation and Pacific Island Affairs, Mr Gordon Bilney, presented a thought-provoking paper on the long-term economic prospects facing the region (Bilney, 1994). Without being alarmist, Bilney pointed to the region's high population growth rates and the

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[1] The 16 members of the Forum Fisheries Agency are Australia, Cook Islands, Federated States of Micronesia, Fiji, Kiribati, Marshall Islands, Nauru, New Zealand, Niue, Palau, Papua New Guinea, Solomon Islands, Tonga, Tuvalu, Vanuatu and Western Samoa.

associated high internal migration from rural to urban areas as leading to growing unemployment and urbanisation problems, with government services struggling to meet the increasing demands being placed on them. He pointed to growing lawlessness and social tensions as people, particularly the young, contend with increasing social and economic expectations. He also noted the diminishing strategic significance of the region following the end of the Cold War and that there was no assurance that the level of external funding coming into the region would be maintained at current levels. Any fall in the level of external funding coming to the region would place further pressure on the economies of the island countries.

It is against this uncertain backdrop that FFA member countries are actively exploring opportunities available to them to promote their economic independence. With a few exceptions, the range of development options available are limited. Fisheries, principally tuna, along with tourism, forestry, and in some cases mining, agriculture and small-scale manufacturing, represent for most countries the only opportunities for economic growth.

2. DEVELOPMENT OF THE LOCALLY-BASED TUNA INDUSTRY

The extension of coastal State jurisdiction from 12 to 200 nautical miles in the late 1970s resulted in Pacific island nations gaining control over rich tuna fishing grounds. As an interim measure, pending the development of their domestic fishing industries, many coastal States entered into bilateral fishing agreements giving vessels from distant water fishing nations access to their extended waters in exchange for a negotiated fee. However, with few exceptions, little substantive progress was made in the following 15 years in terms of developing viable and sustainable tuna-based enterprises in the region.

FFA countries, aware of their limited development options but yet anxious to avoid the bleak futuristic outlook portrayed by Bilney (1994), are intensifying their efforts to extend their involvement in the region's tuna fisheries. Developments are occurring in all sectors of the industry--harvesting, processing and the service sector.

2.1 Harvesting

Although the number of purse seine vessels that are permanently based in an FFA country is growing (currently there are 24), the locally-based fleet accounts for a very small proportion of the total purse seine catch. In value terms, the 1993 catch of the domestically-based vessels represented less than 5% of the regional catch, i.e., $23 million of an estimated $665 million. Furthermore, a number of the domestically-based enterprises have yet to prove their viability and continue to operate with the assistance of government subsidies.

In terms of the longline fishery, there has been spectacular growth in the number of vessels basing themselves in FFA member countries in recent years. Around 600 vessels of 100 GRT or less are now based in Palau, the Federated States of Micronesia or the Marshall Islands. The growth in domestic longlining is not confined to the Micronesian countries--three new enterprises and over 100 vessels are expected to commence operations in Solomon Islands in 1995, around 30 vessels are active in Fiji, and smaller fleets are

operating in Tonga and Cook Islands. Papua New Guinea and Kiribati are also considering options for developing their longline fisheries.

The vast majority of the domestically-based longline vessels are foreign-owned. However, the fact that they are locally-based generates substantial economic benefits for the local economies through the generation of employment, both crewing and on-shore, payment of government charges and taxes, purchases of government-supplied inputs which may include air freight, electricity and water.

Unlike purse seining and longlining, there has been a decline in the number of locally-based pole and line vessels in recent years.

2.2 Processing

The central western Pacific produces around 50-60% of the world's annual supply of canning tuna, with most of the raw material presently transported to canneries in Bangkok and American Samoa. Two canneries are based in FFA countries, Solomon-Taiyo in Solomon Islands and Pacific Fisheries Company in Fiji. Further canning facilities in the region are forthcoming, one currently under construction at Madang in Papua New Guinea and a second being considered in the Federated States of Micronesia.

2.3 Service sectors

The influx of vessels, both purse seiners and longliners, now unloading their catch in ports in the region has created a growing demand for local stevedoring services. It is also expected that as the number and frequency of vessels calling into port increases, the prospects of locally-based engine repairers, net manufacturers, gear and fuel suppliers and so on, relocating to the region will also increase.

A number of FFA countries, especially Kiribati and the Federated States of Micronesia, are training their own people to work on the foreign vessels. Training centres have been established in both countries and there are a number of I-Kiribati and Micronesian crew on Japanese, Korean and Taiwanese vessels. This is an area that offers scope for further development, given the difficulties that Japanese, Korean and Taiwanese vessel owners are having in attracting their own nationals to work on their vessels. As well as the immediate effect of increasing employment opportunities, the at-sea training of local people will facilitate the development of domestic fishing industries in FFA countries in the medium-term.

3. TYPES OF TUNA FISHERIES INTERACTION

Kleiber (1994) categorised the impacts of one fishing activity on another fishing activity into two broad groups: resource-related, whereby there is a direct impact upon the resources available for the second activity, and non-resource-related, such as physical crowding on the fishing grounds and lower market prices.

Hampton (1994) identified the key resource-related interaction issues that are present in the western and central Pacific Ocean. Three types of resource-related interactions were identified:

A. competition for the same stock in the same general area;
B. competition for the same stock but at a different stages of the life cycle; and
C. competition for the same stock but in different areas.

3.1 Impact of Fishing in One FFA Member Country on Another

The migratory nature of all the major tuna resources means that the catch taken in one country may impact upon catches in other countries (type C interaction). The recognition of this likely interaction was in fact one of the principle reasons behind the establishment of the Forum Fisheries Agency, as the Pacific island countries realised that they could not manage the resource independently of their neighbours. A cooperative approach to the management of the tuna fishery was recognised as being essential to ensure the sustainability of the resource.

Regarding the purse seine fishery, a number of FFA member countries became concerned about the rapid expansion of the purse seine fishery in the Western Pacific in the late 1980s and early 1990s. The countries involved agreed that consideration should be given to the formulation of a mechanism to regulate the number of purse seine vessels operating in the region and that a cap be placed on the number of purse seine licences issued. This agreement was formalised with the signing of the Arrangement for the Management of the Western Pacific Purse Seine Fishery (known as the Palau Arrangement) in October 1992 by Federated States of Micronesia, Marshall Islands, Nauru, Palau, Papua New Guinea and Tuvalu. Solomon Islands and Kiribati signed in 1993 and the Palau Arrangement remains open for signature by the remaining FFA countries. The key provisions in the Palau Arrangement are those dealing with the allocation of purse seine vessel licences, with the countries involved agreeing to limit the number of vessels that may be licensed. The cap presently stands at 205 licences, made up of 196 single purse seine licences and nine group purse seine licences.

The Palau Arrangement also establishes the order of priority in which available licences will be issued:

a) first priority will go to domestic vessels as defined for the purposes of the Arrangement;

b) second priority goes to domestic vessels of another Party to the Arrangement, or vessels jointly operated by or on behalf of the Government of the Party in which the vessel is based and one or more other Parties;

c) third priority goes to locally-based foreign fishing vessels, including vessels operating under joint venture agreements;

d) foreign fishing vessels with established access agreements and with good records of compliance will have next priority; and finally

e) last priority will go to new entrants into the fishery and those with poor records of compliance.

Consistent with their stated desire of developing the locally-based fleet, in 1994 the FFA countries involved agreed to a 10% cut in the number of purse seine licences allocated to bilaterally-licensed fleets. This cut will become effective in three years time, removing 12 foreign boats from the fishery. Associated with this reduction, the FFA countries agreed that 12 new licences are to be added to the "domestic/locally-based foreign/FFA member bilateral" category. There are no regionally agreed management measures at present for the longline fishery.

3.2 Competition between the surface fishery and the longline fishery

An issue of critical importance to the region is the possible impact of the surface fishery catches on the catch of the longline fishery. This issue has assumed greater importance in recent years with the expansion in the number of locally-based vessels in both the longline and purse seine fisheries.

As previously outlined, the level of purse seine effort is controlled by the limit on vessel numbers as imposed under the Palau Arrangement, with the cap set at 205. However, with the increasing level of local investment taking place, concentrated in the longline fishery, any negative impact of the surface fishery catch on the longline catch poses the question of whether 205 is an appropriate level at which to set the cap. Should such negative impacts be established, there may be a need to determine which fishery, the surface or the longline, should have priority. This matter will ultimately depend upon the respective economic benefits that the two competing fishing operations generate for the region.

This issue is the subject of a three year research project being undertaken by FFA, the Oceanic Fisheries Programme of the South Pacific Commission (SPC) and the University of Queensland. The project, funded by the Australian Centre for International Agricultural Research, is to examine possible biological and economic interactions among the purse seine and longline fisheries in the Central Western Pacific. The objective in the study is to shed light on the likely combination of purse seine and longline activity that will generate the highest level of returns to the region as a whole. Researchers from the University of Queensland will be largely responsible for the conduct of the study. These researchers will work in close collaboration with FFA and SPC who will provide technical and policy input and guidance. The project is at a very early stage, having commenced in late 1994.

3.3 Competition between the offshore and artisanal fleets

With food-producing and income-earning opportunities limited in many of the small island countries, the artisanal sector is of key importance to many Pacific nations as a source of food and income. Developments that adversely affect the artisanal fishery therefore have implications for the social structure of the island communities.

3.3.1 Kiribati

Concern has been expressed that the increased purse seine activity in Kiribati waters in recent years has adversely affected the catch rates of the artisanal skiff vessels. Although little scientific evidence has been found to support this claim, Kiribati has imposed a limit on the number of licences available to purse seine vessels wanting access to the Kiribati EEZ. This limit, set at 65 vessels, is fully utilised. Additional vessels have sought access to the Kiribati EEZ but they have been rejected on the grounds that there are no surplus licences available.

From a regional perspective, Kiribati's perceived interaction problem has implications for the likely implementation of any future multilateral access arrangement with the distant water fishing nations. Kiribati is a party to the existing multilateral arrangement with the United States[2], involving up to 55 purse seine vessels. This means that 55 US purse seiners could legitimately operate in the Kiribati EEZ, which leaves only 10 additional licences for purse seiners of other nations.

The cost to Kiribati from implementing their 65 vessel policy is represented by any licensing revenue foregone from those vessels in excess of the limit that would otherwise have sought access to the Kiribati EEZ. These losses may be substantial, given the size of the Kiribati economy and that the fee for an annual licence is in the order of A$70,000-90,000. The benefits of the policy are represented by the improvement in the artisanal catch that is attributable to the constrained level of purse seine activity.

A separate paper (Hampton, et al., 1996) outlines the scientific work that has been undertaken to assess the evidence for interaction between the purse seine and artisanal fisheries in Kiribati.

3.4 Competition between the foreign-based and locally-based longline fleets

There has been a tremendous expansion in the number of small-scale longline vessels operating in the central and western Pacific in the last 2-3 years. These vessels are targeting yellowfin and bigeye tunas during fishing trips of around 7-10 days. Once caught, the fish are chilled in ice before being airfreighted for the fresh sashimi market in Japan.

These vessels are in direct competition with the more established foreign-based longline vessels that operate under bilateral access agreements in the EEZs of several FFA member countries. In recent bilateral fisheries negotiations, the fisheries associations that represent the owners of these vessels have claimed that their catch rates have been adversely affected by the influx of the locally-based fleet. Furthermore, they have used this argument to justify a lowering of access fees.

Apart from the increased competition for the same stock, the foreign operators have also encountered problems due to additional crowding on the fishing grounds, i.e., the non-

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[2] Treaty on Fisheries Between the Governments of Certain Pacific Island States and the Government of the United States of America.

resource related problems to which Kleiber (1994) referred. The foreign vessel owners have, for example, cited cases of damaged/stolen gear and of fish being removed from lines.

3.4.1 Palau

There are three locally-based fishing companies in Palau--Palau International Traders Incorporated, Palau Maritime Industries Corporation and Kuniyoshi Fishing Company. The three companies operate in excess of 200 longline vessels, mostly from the People's Republic of China. Palau also has a bilateral access arrangement with four Japanese fisheries associations covering longliners, single and group purse seining and pole and lining. The number of Japanese longline vessels seeking access to Palau has been steadily declining in recent years, as shown in Table 1.

Table 1. Number of Japanese longline vessels seeking access to Palau, 1993-95.

	1993	1994	1995
Longliners (< 20 GRT)	52	32	23
Longliners (>20 GRT)	5	1	0

There are undoubtedly numerous factors influencing the decline in the number of Japanese vessel owners wanting access to Palau but the growing number of locally-based vessels is likely to be one of the most significant.

The growth in the locally-based fleet is incurring a cost to Palau to the extent that the increased number of locally-based vessels is deterring other vessel owners from paying fees for the right to fish in Palau's EEZ. This cost is represented by the access fees foregone. However, the locally-based vessels, in conjunction with the fishing company, generate benefits for Palau in the form of the direct taxation of the companies, indirect taxes, payments for government services, the employment of Palauan citizens and the spending and taxing of alien workers. These benefits are spread through both the public and the private sectors. The issue for Palau to consider is whether the benefits received from the foreign companies are likely to be greater than the returns that would otherwise be received from alternative users of the fish resource, namely the foreign bilateral vessels.

The Federated Sates of Micronesia and Marshall Islands are confronted with exactly the same issue that Palau has encountered: how to maximise the returns from their tuna resources given an emerging locally-based longline fleet and an established bilaterally-licensed foreign fleet. The issue is an economic matter, to be decided primarily by identifying which of the two fleets offer the greater benefit to the country concerned.

3.5 Competition between the foreign-based and locally-based purse seine fleets

The FFA member countries' desires to develop their domestic tuna industries are not confined to the longline fishery and several countries are actively promoting growth in the

locally-based purse seine fleet. In 1994 there were eight purse seiners based in the Federated States of Micronesia, five in Papua New Guinea (with many more expected when the Madang cannery is complete), 13 in Solomon Islands and one each in Kiribati and Vanuatu.

These locally-based vessels are in competition with the foreign based vessels for the skipjack stock in the central and western Pacific, and unrestricted licensing of foreign purse seiners would adversely impact upon catch rates and hence profitability of the locally-based fleet. The Palau Arrangement, described earlier, puts an upper cap on the extent of this competition by limiting the number of licences that are available to foreign purse seine vessels. Some countries, such as Papua New Guinea, exclude foreign bilateral vessels from certain waters in an attempt to lessen any adverse impacts of the bilateral fleet on their local vessels. Similarly, the policy in Solomon Islands is, in most cases, to only issue licences to purse seine vessels that are locally-based in the country. There are no licences available to foreign-based purse seiners, and foreign-based vessels operating under the terms of the Multilateral Treaty on Fisheries are denied access to around 90% of the Solomon Islands EEZ.

Similar to the situation regarding longlining, the cost to the countries involved of these policies is the foregone access fees that could otherwise have been obtained if access was unrestricted. This cost needs to be considered against the benefits that the policies generate, more specifically, the higher catch rates, and hence profits, for the locally-based fleet.

3.6 Market competition between the same fleets

In June 1993 FFA countries restricted those fishing vessels that are licensed to operate in a FFA country from unauthorised at-sea transhipment. One of the reasons for the high seas transhipment ban was the perceived need to alleviate some of the build-up in fishing pressure experienced in the late 1980s and early 1990s. Vessels are now required to steam from the fishing grounds to the designated transhipment port, and then steam back to the grounds, before they can continue fishing. It is estimated that fishing time might have fallen by as much as 20% as a result. Coinciding with the impact of the transhipment ban, there was a marked turnaround in tuna prices, as illustrated in Figure 1. Although there are a multitude of factors influencing tuna prices, it is probable that a significant portion of the price rise was attributable to the transhipment ban.

The joint FFA-SPC-University of Queensland study, discussed previously, will also examine the extent to which changes in tuna supplies from the central western Pacific affect the world price for canning tuna. If the region is found to have some degree of market power, this information can be used to identify the size of the tuna harvest and number of purse seine vessels which are likely to result in the highest level of income for the region. The development of bioeconomic fisheries models that explicitly account for the biological impacts as well as the different cost and revenue functions of the competing fishing methods will provide valuable support to managers in this regard.

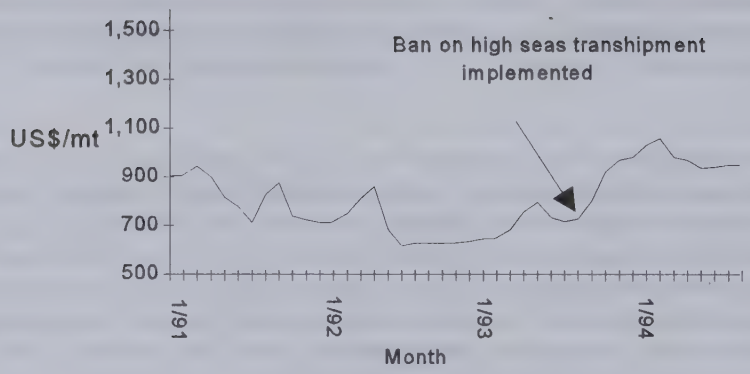

Figure 1. American Tuna Sales Association (ATSA) prices for purse seine caught skipjack tuna (4.0 - 7.5 lb).

Market competition is obviously not unique to the purse seine fishery; Japan in particular claims that the growth in fresh sashimi exports emanating from the Pacific has led to a general downturn in tuna prices in Japan. Pacific island exporters have been sheltered from the price fall in the Japanese market by the continued appreciation of the yen. However, as with the purse seine fishery, more work is needed to assess the significance of the increased supplies from the Pacific on Japanese tuna prices.

4. CONCLUDING COMMENTS

As FFA countries become more involved in the tuna fisheries, their need for proper fisheries management intensifies. Management, in this sense, is both a scientific and an economic concern, involving more than resource sustainability; it also involves maximising the flow of benefits generated from the resource.

The development of the locally-based tuna industries in the FFA countries also increases the importance of understanding the various interaction effects present in the fishery. While the increased number of vessels operating in the region creates development opportunities for FFA countries, there is a point after which any additional boats start to have a negative impact on the benefits generated from the fishery. For example, concern has been expressed that many of the vessels joining the locally-based fleet are new to the region and represent an increase in the total size of the fleet rather than the displacing of existing foreign vessels. This is of particular concern with respect to the substantial growth in the locally-based longline fleet.

Greater competition on the grounds also reduces the catch rates and, hence, profitability of all vessels. Crowding is a potential problem, both at sea and in port, and increasing friction between the locally-based and foreign licensed fleets is already apparent. Environmental concerns, particularly with more vessels now using ports in the region, are also intensifying. On the marketing side, the rapidly-increasing amounts of fresh tuna being airfreighted to the Japanese market can also be expected to put downward pressure on tuna prices, to the detriment of all enterprises.

More information, both scientific and economic, is needed to counter these possible undesirable aspects of the FFA countries' more active participation in the tuna fisheries of the Pacific. More detailed cost-benefit analyses will be required in the future so that fisheries managers will be able to incorporate the impacts of these various interaction effects into their decision-making. This should enable managers to make more-informed and, hence, better decisions.

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RECENT DEVELOPMENTS IN THE TUNA FISHERIES OF THE FEDERATED STATES OF MICRONESIA

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ABSTRACT

This paper provides a general overview of the 1993 fishing year in the Federated States of Micronesia (FSM), along with comparative statistics from previous years as a gauge to the current status of the three principal fisheries operating in the FSM EEZ, i.e., purse seine, longline and pole-and-line fisheries. Monitoring these fisheries is needed to identify interactions among fisheries, and to identify the potential impacts of these fisheries on devloping domestic tuna fisheries. A synopsis of recent developments in FSM domestic fisheries is included, along with information on current national and regional research projects.

1. INTRODUCTION

The 200 mile Exclusive Economic Zone (EEZ) of the Federated States of Micronesia (FSM) covers roughly 1,000,000 square kilometres of ocean. It is one of the largest fishing zones in the central and western Pacific Ocean, with rich fisheries resources. Revenues derived from these fisheries resources are the number one source of income for the nation and hence the number one priority. There has been a dramatic increase in the harvest of tuna from the FSM EEZ, and from the western Pacific as a whole, in the last 10 years. Coupled with this increase has been a general concern by many Pacific island countries that the regional stocks of tuna are reaching or exceeding the maximum biological sustainability. To address this situation, the Micronesian Maritime Authority (MMA), the main licensing and monitoring agency of the FSM National Government, requested in 1990 that the Food and Agricultural Organization of the United Nations retain an independent consultant to review the tuna fisheries operating in the FSM. The results of this study (Sibert, 1990a, 1990b), suggested that there was no compelling evidence to support effort reduction for the purpose of biological conservation of the tuna stocks. The study also recommended annual harvest levels and corresponding effort levels, by gear type and species, which could be sustained in the FSM EEZ for the near future. A total harvest of 193,000 metric tons (mt) was proposed as being biologically sustainable for the FSM tuna fishery (purse seine 145,000 mt; longline 16,000 mt; pole-and-line 32,000 mt).

Since the time of this study, the FSM tuna fishery has undergone some dynamic changes in the composition of the foreign fishing fleets operating in the EEZ and in the magnitude

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and distribution of catch amongst these fleets. During the calendar year 1993, a total of 173,082 mt of the principal market species of tuna and billfishes were harvested from the FSM EEZ (purse seine 149,881 mt; longline 16,628 mt; pole-and-line 6,573 mt). The majority of the catch was taken by the primary distant water fishing fleets of Japan, USA, Taiwan, China and Korea, with a combined licensed capacity exceeding 600 vessels. This figure must be regarded as a conservative estimate of total catch given the regionally recognized under-reporting and non-reporting of catch by the Taiwanese and Korean purse seine fleets (Lawson, 1992). It should be noted that there has been substantial improvement in the catch reporting requirements by the Taiwanese and Korean fleets primarily as a result of increased pressure from the Pacific Island countries which have bilateral access agreements with these fleets (A.D. Lewis, SPC, pers. comm.). The June 1993 regional ban on high-seas transshipment of purse seine caught tuna has also resulted in improved monitoring of the foreign fleets that are now required to transship their catches from regionally designated ports. Nonetheless, given that there no doubt still exists some level of under-reporting and non-reporting by the foreign fleets, the 1993 total catch for the FSM EEZ has most likely met or exceeded the 1990 proposed harvest total of 193,000 mt.

Revenues from the pelagic tuna fisheries have been generated mainly through the licensing of foreign distant water fishing vessels. More recently, the government of the FSM has recognized the need to develop and strengthen the domestic fishing industry and as a result there has been a greater emphasis on investments towards infrastructure development and employment opportunities within the four states of the FSM. The FSM government collected in excess of US$20,000,000 in licensing fees from the primary distant water fleets for access to the FSM EEZ during 1993. Substantial economic benefits were also realized from the growing purse seine transshipment activities in the FSM port of Chuuk along with the rapidly developing, longline transshipment operations taking place in all four states of the FSM. Given the disparity in catch levels between the purse seine and longline fisheries operating in the FSM EEZ, while at the same time acknowledging the near parity of economic benefits derived from the two fisheries, there is now a greater awareness of the potential economic yield of the fisheries as a factor when considering the more publicised concerns over biomass yield.

The FSM's National Fisheries Corporation (NFC) has invested millions of dollars in the design and construction of full service longline transshipment bases. These bases, located in Chunk and Yap States, were inaugurated and put into service during the last quarter of 1994 with plans to accommodate a maximum of 100 foreign and domestic longline vessels at each base. The NEC is also nearing completion of a joint-venture agreement with the Japanese longline industry that will base a significant number of Japanese longliners in FSM ports along with providing vital assistance with air transportation of FSM fish exports to the Japanese sashimi market.

Given the current and future plans of the FSM to develop its own domestic fishing industry while at the same time maintaining the hard currency revenues derived from the licensing of foreign fishing vessels, there is concern amongst resource management personnel and fisheries policy makers that the increasing catches in the FSM EEZ may be unsustainable both in a biological and economic sense. Of equal concern is what this high level of catch and effort may mean in the way of interactions amongst the various fisheries operating in our waters. It is the desire of the FSM to arrive at an equitable and sustainable

balance amongst the various fisheries operating in the zone, both in terms of maximizing benefits (revenues, employment opportunities, etc.) and in assuring that our fisheries resources are allocated on a sustainable basis. In order to achieve these objectives, we need to have conclusive scientific evidence demonstrating the nature of the fisheries interactions taking place in the FSM EEZ and the implications that such interactions have on the dynamics of the various fisheries

2. CURRENT LICENSING AGREEMENTS WITH DISTANT WATER FISHING NATIONS

The following foreign and domestic Fishing fleets are currently licensed to operate in the EEZ of the FSM (figures are approximations as some negotiations are still ongoing):

• Taiwan Purse Seine	43 vessels
• Korea Purse Seine	31 vessels
• Japan Purse Seine	32 vessels (not including 1-3 group purse seine operations).
• USA Purse Seine	42 vessels
• FSM Purse Seine	8 vessels
• Japan Pole-and-line	36 vessels
• Japan Longline	Per vessel/per trip system number varies by month, ~110 vessels
• Taiwan Longline	~75 vessels
• Mainland China Longline	~265 vessels
• FSM Longline	9 vessels (6 NFC, 2 Chunk State, 1 Pohnpei private)

3. 1993 TUNA CATCHES IN THE FSM EEZ

The total 1993 catch for the principal market species of tuna harvested in the EEZ of FSM was approximately 173,082 metric tons (mt). This represents an increase of 24% over the 1992 total of 139,915 mt. The 1993 total shows a 25% increase over the 5-year average of 138,008 mt dating from 1988-92 (see Table 1). This increase is attributed almost exclusively to higher purse seine and longline catches while pole-and-line catches have decreased markedly. The relative proportion of the FSM tuna catch by flag and by gear type are shown in Figures 1-3.

Skipjack tuna accounted for 59% (~102,000 mt) of the 1993 total with yellowfin next at 37% (~64,000 mt). Bigeye tuna harvested primarily by the longline fishery contributed an additional 4% (~7,000 mt) to the total. A small amount of bigeye tuna (~10%) is captured by the purse seine fishery and reported as yellowfin tuna in the catch records.

Table 1. Tuna catch in the FSM EEZ, by gear type, 1988-93.
Source: vessel catch reports.

	Catch (mt)			
Year	Purse Seine	Longline	Pole-and-Line	Total
1988	131,637	10,037	13,160	154,834
1989	92,167	13,031	20,472	125,670
1990	102,789	14,886	10,547	128,222
1991	107,713	10,278	23,410	141,401
1992	123,302	13,470	3,143	139,915
Total	557,608	61,702	70,732	690,042
5-Year Avg.	111,522	12,340	14,146	138,008
1993	149,881	16,628	6,573	173,082

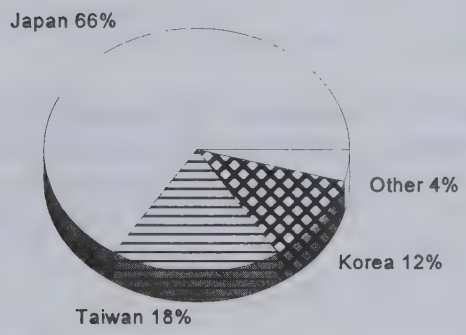

Figure 1. 1993 FSM EEZ catch composition by flag.
Other incudes USA (1.5%), FSM (1.5%) and China (1%).

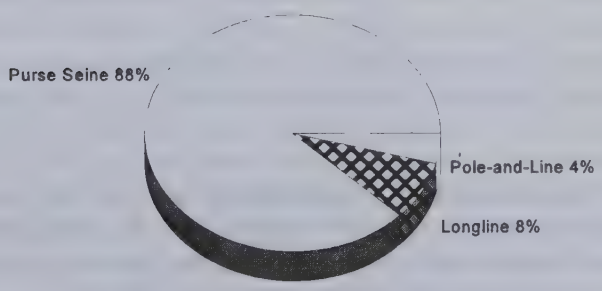

Figure 2. 1993 FSM EEZ catch by gear.
PS=purse seine; LL=longline, PL=pole-and-line.

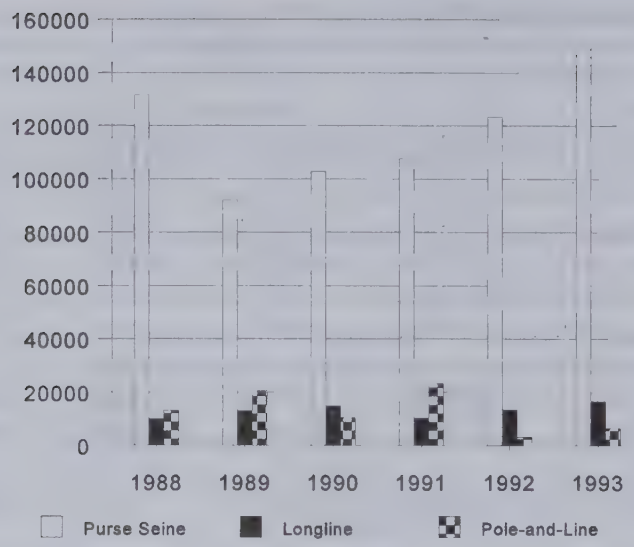

Figure 3. Tuna catches in the FSM EEZ, by gear type, 1988-93.

3.1 Purse Seine Fishery

The majority of the FSM tuna catch for 1993, roughly 88%, was taken by foreign and domestic purse seine vessels licensed to operate in the FSM EEZ. The Japanese purse seine fleet, accounted for 89,710 mt or 62% of the total purse seine harvest and 52% of the entire FSM harvest (Table 2). The previous 5-year catch average (1988- 1992) for the Japanese fleet was 87,180 mt.

Table 2. Japan purse seine catch and effort in FSM EEZ, 1991-94.
Source: vessel catch reports.

Year	Days Fished	Total Catch (mt)	Avg. CPUE (mt/day)
1991	3,706	90,509	24.4
1992	2,742	82,919	30.2
1993	4,403	89,710	20.3
1994	1,615	40,313	24.9

The Taiwanese purse seine fleet harvested approximately 36,358 mt from the FSM EEZ in 1993, a substantial increase over the 1992 totals (Table 3). Some of the increase is undoubtedly attributed to the improvement in complying with the catch reporting provisions of the Minimum Terms and Conditions for access to the FSM EEZ.

Table 3. Taiwan purse seine catch and effort in FSM EEZ, 1991-94.
Source: vessel catch reports.

Year	Days Fished	Total Catch (mt)	Avg. CPUE (mt/day)
1991	0	0	n/a
1992	2,059	22,008	10.6
1993	2,494	36,358	14.7
1994	689	11,690	17.0

The Korean purse seine data for 1993 (Table 4) should be viewed as a conservative estimate of total catch and effort due to the fact that allegations of under-reporting and non-reporting of catch and effort have been asserted against the fleet. As with the Taiwan purse seine fleet, there has been considerable improvement in the Korean purse seine catch reporting for the 1994 calendar year, as witnessed by the substantial increase in CPUE for the preliminary 1994 data.

Table 4. Korea purse seine catch and effort in FSM EEZ, 1991-94.
Source: vessel catch reports.

Year	Days Fished	Total Catch (mt)	Avg. CPUE (mt/day)
1991	0	0	n/a
1992	0	0	n/a
1993	1,756	21,549	12.3
1994	594	11,185	18.8

The USA purse seine fleet spent only 162 days in the FSM EEZ during 1993 harvesting 2,576 mt of tuna (SKJ = 1,229, YFT = 1,347). The small domestic purse seine fleet of the FSM, currently numbering 8 vessels, harvested 1,971 mt of tuna in 1993 with 285 days of effort (SKJ = 1,193, YFT = 778). The data for the FSM purse seine fleet is incomplete with catch reports still pending from 1993 and 1994.

It should be noted that commencing June of 1993, a region-wide ban on the high-seas transshipment of purse seine caught tuna was instituted which may have resulted in lowering the overall 1993 regional catches by the Taiwanese and Korean purse seine fleets. This reduction in catch was a consequence of increased turn around times for unloading the tuna catches in port versus the previous high-seas transshipment operations. The high-seas transshipment ban did not have a major impact on the Japanese and US purse seine catches as these fleets have not, as a rule, transshipped their catches on the high seas in previous years.

3.2 Longline Fishery

The 1993 FSM EEZ longline catch of 16,628 mt represents a 19% increase over the 1992 harvest of 13,470 mt. The previous 5-year catch average (1988-1992) for the longline fleet was 12,340 mt. There has, however, been some dynamic changes in terms of the composition of the various foreign fleets fishing for the Japanese sashimi export market. Beginning in 1992, Taiwanese and mainland Chinese longliners began using FSM ports as transshipment bases to export their catches to Japan via Guam and/or Saipan.

The Japanese portion of the FSM longline catch for 1993, estimated at 10,143 mt, has shown a slight decrease over the 1992 catch of 10,480 mt (Table 5). The Japanese longline fleet, however, has increased their effort in 1993 by roughly 15% over 1992 levels giving a noticeable drop in their CPUE for the target species of yellowfin and bigeye tuna. Preliminary Japanese longline data for the 1994 calendar year demonstrates a similar CPUE for yellowfin (0.75) and bigeye (0.44) from the FSM EEZ.

Table 5. Japan longline catch and effort in FSM EEZ, 1991-93.
Source: vessel catch reports.

Year	Hooks x 100	Total Catch* (mt)	YFT CPUE (fish/100 hooks)	BET CPUE (fish/100 hooks)
1991	235,096	10,178	0.83	0.54
1992	204,372	10,561	1.00	0.55
1993	239,821	10,143	0.73	0.48

*Total catch includes all species, e.g. billfishes.

The Taiwanese portion of the FSM longline catch for 1993, estimated at 3,011 mt, represents an increase of 18% over the 1992 catch of 2,517 mt (Table 6). This increase, however, came as a result of a 43% increase in the number of hooks set which reflects a marked decrease in the overall CPUE for the target species of yellowfin and bigeye tuna. Preliminary Taiwanese longline data for the 1994 calendar year (FSM EEZ) demonstrates a similar CPUE for yellowfin (0.41) and bigeye (0.54).

Table 6. Taiwan longline catch and effort in FSM EEZ, 1991-93.
Source: vessel catch reports.

Year	Hooks x 100	Total Catch* (mt)	YFT CPUE (fish/100 hooks)	BET CPUE (fish/100 hooks)
1991	4,668	343	0.57	0.54
1992	35,483	2,517	0.84	0.54
1993	62,252	3,011	0.42	0.50

*Total catch includes all species, e.g. billfishes.

The Mainland Chinese longline vessels began limited operations in the FSM EEZ during 1992 with assistance from a Taiwanese longline company. Fishing gear technology and knowledge of the fishing operation was transferred to the Chinese by the more experienced Taiwanese fishermen which greatly improved their initial catch rates and success in the FSM EEZ. During 1993 a certain segment of the Mainland Chinese longline fleet began operations independent of the Taiwanese company which may have resulted in a decreased CPUE as reflected in the overall 1993 figures for the Chinese. Preliminary Chinese longline data for the 1994 calendar year (FSM EEZ) demonstrates a decrease in the CPUE for yellowfin (0.39) and no change for the CPUE of bigeye (0.45) (Table 7).

Table 7. Mainland China longline catch and effort in FSM EEZ, 1992-93.
Source: vessel catch reports.

Year	Hooks x 100	Total Catch* (mt)	YFT CPUE (fish/100 hooks)	BET CPUE (fish/100 hooks)
1992	6,270	402	0.60	0.52
1993	71,128	3,384	0.46	0.45

*Total catch includes all species, e.g. billfishes.

3.3 Pole-and-Line Fishery

The 1993 Japanese pole-and-line catch in the FSM EEZ of 6,573 mt represents a more than 100% increase over the 1992 catch total of 3,143 mt (Table 8). The previous 5-year catch average for the Japanese pole-and-line fleet in the FSM EEZ was 14,146 mt. The main reason for the declining trend in catch has been a reduction in the size of the pole-and-line fleet and the corresponding decrease in fishing effort. For example, the peak catch during the previous 5-year period was 23,408 mt harvested in 1991. A total of 2,599 fishing days were logged by the Japanese pole-and-line fleet during 1991 versus 815 fishing days for 1993.

Table 8. Japan pole-and-line catch and effort in FSM EEZ, 1991-94.
Source: vessel catch reports.

Year	Days Fished	Total Catch (mt)	Avg. CPUE (mt/day)
1991	2,599	23,410	9.0
1992	557	3,143	5.6
1993	815	6,573	7.6
1994	664	4,598	6.3

4. RESEARCH PROJECTS

4.1 Tuna Fisheries Interaction and Status of Stocks in the FSM EEZ

With catch and effort in the FSM EEZ approaching, and possibly exceeding, the proposed 1990 annual harvest levels (see Table 9), the MMA has commissioned a study to revisit the question of the current level of exploitation on the tuna stocks in the FSM EEZ with particular interest directed towards quantifying the magnitude and scope of potential fisheries interactions. As with the 1990 study, the annual harvest levels, by gear type and species, will be recommended for management purposes. The study is currently in progress with completion and final report slated for the first quarter of 1995. Funding for the study has been provided in part by the Oceanic Fisheries Program of the South Pacific Commission with additional contributions from the FSM national government.

The MMA has requested and received cooperation from the governments of Palau, Marshall Islands and Papua New Guinea in providing access to catch and effort data from their respective EEZs for the purposes of this study. In addition, the government of Japan has provided historic high seas catch and effort data upon request for use in the study. Since the 1990 study, there have been noticeable improvements in the collection of size-frequency and species composition data from the MMA port sampling and observer programs which should enhance the present study.

Table 9. Proposed and actual 1993 harvest and effort levels for FSM tuna fisheries. Source: Sibert, 1990 a; 1990b.

Gear	Proposed Harvest Level (mt)	1993 Catch (mt)	Status	Proposed Effort Level	Actual 1993 Effort	Status
Purse seine	145000	149881	exceeded by 3%	5800 to 8400 days	9100 days	exceeded upper range by 8%
Longline	16000	16628	exceeded by 3%	36 to 44 million hooks	37.3 million hooks	within lower range
Pole-and-line	32000	6573	under by 79%	5600 days	815 days	under by 84%
Total	193000	173082				

4.2 Yellowfin Tuna Reproduction Study

The Micronesian Maritime Authority has played a vital role in the design and implementation of a regional study aimed at investigating the reproductive biology of yellowfin tuna, *Thunnus albacares*, from the western and central Pacific. The funding for this project is being provided by the University of Hawaii, School of Ocean and Earth Sciences (SOEST), under grant money received from the US Department of Commerce. The following investigators are involved in the research:

Coordinator: David Itano, Fisheries Biologist, University of Hawaii, JIMAR

Collaborators: John Hampton, Principal Fisheries Scientist, South Pacific Commission
Craig Heberer, Tuna Biologist, Micronesian Maritime Authority
Sachiko Tsuji, Fisheries Biologist, National Research Institute of Far Seas Fisheries Japan
Richard Shomura, Fisheries Biologist, University of Hawaii, Hawaii Institute of Marine Biology (HIMB), Hawaii
Gordon Grau, Professor of Zoology, University of Hawaii, HIMB, Hawaii

Objectives of the research:

- assess the role of reproductive behaviour in determining cycles of vulnerability of yellowfin tuna to surface and subsurface gear;
- estimate the size at first maturity, spawning frequency and fecundity of yellowfin tuna for different areas and seasons in the western Pacific and Hawaiian waters;
- define major spawning areas and seasons for yellowfin tuna in these areas, and
- estimate the sex ratio of yellowfin tuna as a function of size.

The time frame for sampling will encompass two complete years which will provide the necessary temporal range to test the hypothesis regarding spawning seasonality and inter-annual variability. The sampling phase began 1 April 1994, at which time the various fisheries observers around the regions carried the sampling kits to sea with them. Samples of yellowfin eggs will be collected from fish ranging in size from 50-150 centimetres fork length by MMA, NMFS and FFA fisheries observers on board foreign and domestic longline and purse seine vessels. In addition, Japanese observers will collect samples from longline training vessels and fresh samples will be collected by port samplers in the Philippines and Hawaii.

The reproductive parameters of the sampled fish will be determined through microscopic examination of prepared slides. At this point, over 1,500 samples have been stained, sectioned and mounted on microscopic slides. Over 1,000 of these slides have been examined and analysed. Preliminary results are forthcoming.

5. FISHERIES DEVELOPMENT PROJECT IN THE FSM

5.1 The National Fisheries Corporation (NFC)

One of the main developmental thrusts of the NFC is to create a domestic fishing fleet whereby Micronesian citizens can become involved in the fishing industry through employment and/or investment opportunities. To this end, the NFC owns and operates a small fleet of longline vessels based in the various FSM ports targeting the Japanese sashimi grade tuna export market. The vessels are crewed mainly by Micronesian citizens, including the skilled positions such as captains and chief engineers.

Currently, the NFC has six longline vessels based at the Chuuk longline transshipment base. Future plans include the acquisition of four new longline vessels early in 1995 (three

for Kosrae Sea Ventures) followed by a fleet expansion program that aims to incorporate at least two new vessels per year into the fishery. NFC continues to play an important role in manpower development for the domestic fishing industry with assistance from the Japanese OFCF training program at the Micronesian Maritime and Fisheries Academy in Yap State.

Completion of the joint venture NFC/Chunk State Longline Transshipment Base (Chuuk Fresh Tuna, Inc.) will have a substantial positive impact in terms of increased employment opportunities as well as increased revenues for the FSM States. This base will be able to handle 100-120 longline vessels with the intent to supply these vessels with all of the necessary elements of the longline operation. Some of these elements include ice, fuel, oil, water, bait, and stevedoring services for the transshipment operations.

A similar joint venture NFC/Yap State Longline Transshipment Base (Yap Fresh Tuna, Inc.) became operational at the end of August 1995 and will also handle from 100-120 vessels.

5.2 Pohnpei Fisheries Corporation (PPC)

The PFC was established in November 1992 as part of a US$22.5 million loan package that includes a modern fish processing facility and assorted infrastructure development projects aimed at creating a domestic value-added fish processing industry in the State of Pohnpei. The PFC is a public corporation owned entirely by the Pohnpei state government, and must be privatised within three years in accordance with a privatization plan approved by the Legislature. The Fish Processing Facility was constructed and initially managed by the Danish firm Sabroe. The operational plan includes the production of the following products:

- fresh loins from yellowfin and bigeye tuna and other pelagic species such as marlin, swordfish and shark
- frozen loins and steaks
- smoked products
- pre-cooked/prepared products
- block frozen fillets from tuna and skipjack

To procure a sufficient supply of raw material at a cost effective price, the PFC has entered into an agreement with a foreign longline company to base up to 50 Mainland Chinese longline vessels in Pohnpei. The first of these vessels arrived in early May with large scale export of value-added products scheduled to begin in July 1994. Beginning in August 1993, the PFC initiated some limited export sales to Japan and Guam and product was sent to an FDA-approved laboratory in the USA for analysis. The results were very positive and the plant and its products are in compliance with FDA standards which will open up the potential to begin exports to the huge value-added fish product market in the USA.

5.3 Micronesian Longline Fishing Company (MLFC)

The government of the FSM is negotiating a US$6.5 million loan from the Asian Development Bank to create a private sector longline fishing company--the MLFC. The

intent is to procure seven new longline fishing vessels to be operated by all Micronesian crews with shares in the company available only to Micronesian citizens. One of the vessels will be used as a training vessel for the Micronesian Maritime and Fisheries Academy program (MMFA). The MMFA program will be expected to provide the training for Micronesian citizens in all aspects of the longline operation. Construction and procurement of the vessels will be put out to international competitive bid. The loan package includes US$500,000 for technical assistance in the areas of conservation and resource management.

5.4 Yap Fishing Corporation

The Yap Fishing Corporation has continued to operate profitably in the western Pacific purse seine tuna fishery. The company currently has five seiners fishing in the region which provide employment opportunities for a large number of Micronesian citizens.

5.5 The Micronesian Maritime and Fisheries Academy (MMFA)

With the substantially increased level of domestic fisheries development the MMFA will continue to play a vital role in success of the domestic industry in the FSM. The MMFA is currently funded by the FSM government and the State of Yap with the Pacific Missionary Aviation Corporation handling the day to day management of the Academy. At the moment the Japanese Overseas Fisheries Cooperative Foundation (OFCF) has provided some fishing instructors to the MMFA to provide the students with intensive hands-on training in the all aspects of longline and purse seine fishing operations. The OFCF has also donated a substantial inventory of fishing equipment to the MMFA for use in the training programs.

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REPORT GENERATION AND DATA DISPLAY FROM THE NMT MEMORY TAG: A SOFTWARE DEMONSTRATION

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ABSTRACT

The NMT Memory Tag promises to provide researchers with fisheries data never before obtainable. Implanted in a large pelagic fish such as a tuna or swordfish, the tag will record depth, internal temperature, external temperature and sunlight intensity every two minutes for as long as 10-12 years, enabling researchers to determine the position of the fish from day to day and giving them a unique window on the fish's behaviour.

1. INTRODUCTION

1.1 Tag Description

The Northwest Marine Technology (NMT) Memory Tag is primarily intended to be attached to or implanted in a large pelagic fish such as a tuna or swordfish to determine and record its position and key environmental variables every day for a period of years. When recovered and interrogated it will yield that position information along with statistical summaries of all data measured and a detailed time series record of a portion of the mission.

The tag is housed in a stainless-steel cylinder 16 mm in diameter by 100 mm long and weighs 52 grams. A thin, flexible measurement stalk 2 mm in diameter is attached to one end (stalk length is custom, based on users' needs), and when the tag is implanted the stalk extends through the skin of the animal to trail in the water. The end of the stalk houses the light sensor and the sensor for external temperature. The pressure sensor and the sensor for internal temperature are in the body of the tag.

The tag uses times of sunrise and sunset to determine longitude and the sea temperatures at standard depths to determine latitude. This approach is presented in Smith and Goodman (1986). As first proposed by NMT in 1987, the tag does intelligent onboard data processing to reduce memory requirements. The tag extracts measured data from each day and records in a *day log* the comparatively small amount of information required to fix position, plus some additional diagnostic information such as noon light intensity and water clarity. The resulting day log is compact enough so that it can log every day of a multi-year mission and never lose data for lack of memory space.

Either NMT or the user can handle the tasks of initially setting parameters and of reading data from a recovered tag. Host software running on an IBM-compatible personal computer communicates with the tag through an adapter to do either task. The data file

from a recovered tag is initially in compact binary form, maximum size 257K, which is easy to handle and store. A second program translates the compact data record into a set of printable reports. A third program provides graphical display of the data for easy browsing, and generates various kinds of graphical output.

2. MEMORY TAG DATA LOGS

The tag combines 3 types of logging to maximize the information gained from a long mission. The tag is dormant much of the time, but wakes up every 128 seconds, takes measurements and stores them into a *Time Series Log*. Every 24 hours the tag reduces the day's data to a summary sufficient to help determine the tag's position, and stores this information into a *Day Log*. All readings are also tallied and stored in a *Histogram Log*, which maintains a record of the number of times each possible value was measured in each of the data channels. While the Time Series Log may overflow on a long mission, resulting in lost data, the Day Log and Histogram Log cannot overflow, and will preserve information from every data measurement taken since the tag was initialized.

2.1 Day Log

The Day Log is the primary position record, and holds a twelve-byte entry for each day of a mission. Primary quantities recorded are the times of sunrise and sunset, and the temperatures at the surface, at 61 m (200 ft) depth, and at 122 m (400 ft). These standard depths can be changed as a user option. The record also contains some engineering information, and a cross-reference to the day's data in the time series log. Seven years' worth of storage space is allocated to the primary day log. Even after this initial log space fills up, no day log entries are lost. Instead the log is expanded into space otherwise used for time series records, converting time series log into day log. This overwrites 1.6 days (1100 records) of the oldest time series for every additional year of mission beyond the nominal seven years.

2.2 Histogram Log

The most compact data summary is a set of histograms which tally the number of occurrences of every possible data value in each measurement channel. These tallies are based on all measurements taken since the tag was initialized. For example, one can learn from the histograms the extreme measured values of depth and temperature and the fraction of time the animal spent, say for example, below 250 metres depth.

2.3 Time Series Log

The remaining memory, 215 kilobytes, is devoted to a Time Series Log containing four-byte records of raw data. The user may specify the rate at which data is recorded by setting the Time Series Log Interval (N). Data is always *measured* every 128 seconds, 675 times per day; the user can choose to *record* one out of every N of these measurements. For example, if the user chooses to record every seventh measurement (N=7), a new record will be added about every 15 minutes.

The Time Series Log has two parts. Section A fills up with the first data measured and does not change thereafter. Section B fills after Section A, but when it is full, new data begins to overwrite the oldest data in that section. Thus, the Time Series Log preserves the very first data measured, and the last data measured. The user may choose how much of the available space to devote to each section.

3. TAG COMMUNICATION KIT

Tags are delivered with the clock and all parameters set as requested by the user, and are ready to use. There is no way to turn them off, so it is not possible to release an inactive tag. The NMT Memory Tag Connection Kit contains the necessary hardware and software to communicate with the tag and read its data. The two software applications supplied with the kit, *HOST.EXE* and *READABLE.EXE* run under MS-DOS on a IBM-compatible personal computer. This communication kit has been successfully tested on a wide variety of computers.

Using *HOST.EXE*, the user may adjust the tag's parameters to custom-fit its operation to the mission's need and clear the logs just before the tag is released. When the tag is recovered at the end of a mission, *HOST.EXE* is used to download the stored data from the tag into a compact data file.

The data download yields a binary file, size 257 Kbytes or less, intended for easy storage on the floppy disk of the minimal portable computer which is likely to be along in the field. *READABLE.EXE* is used to translate the compact binary data into a set of formatted text files, which are easily printed or imported into any word processing program. The reports contain control codes which allow the user to easily write a custom program to read the reports from disk and perform further processing of the data.

4. GRAPHICAL DISPLAY

Still another program called DATAPLOT, presently under development and nearing completion, displays the log contents graphically. This program runs under MS Windows and allows the user to browse through the three logs, zooming in on areas of interest. Individual graphs can be printed directly or saved as Windows metafiles for import into other Windows applications.

5. SUMMARY

The NMT Memory Tag is more than a simple data logger. It has sensors that are carefully adapted to solve the real problems of fixing the position of pelagic fish. It does intelligent data processing onboard and keeps a day log compact enough so that it never loses position information to data overflow. Finally, it is part of a complete system of hardware and software which presents data to the user in a convenient form, ready to use.

One of the challenges of the bounty of data returned by the Memory Tag is finding an efficient way to scan all the data and isolate those parts which are of the most interest. This problem is solved by a third application called *DATAPLOT*, currently under development and nearing completion. *DATAPLOT,* running under Microsoft Windows, allows the user

to browse through a graphical representation of the Memory Tag data, zooming in and out of the details of the logs. The graphs may be printed directly, or saved to disk as Windows metafiles and imported into other Windows applications.

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AN INDEXED BIBLIOGRAPHY OF PAPERS ON TAGGING OF TUNAS AND BILLFISHES: SUPPLEMENT 1

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This report is a supplement to the first indexed bibliography of papers on tagging of tunas and billfishes (Bayliff, 1993a), which was printed and distributed with financial assistance received from the FAO program, Cooperative Research on Interactions of Pacific Tuna Fisheries.

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This publication includes 40 papers and two abstracts of papers presented at the Second FAO Expert Consultation on Pacific Tuna Fisheries, held in Shimizu, Japan, from 23 to 31 January 1995. The objectives of the consultation were to review and integrate the outcome of studies on tuna fisheries interactions; to summarize the extent of tuna fisheries interactions and unresolved research problems; and to formulate guidelines for research on tuna fisheries interactions. Topics covered by the papers presented in this publication include: reviews of tuna fisheries interactions and research on the interactions, including methods for their study; new methods for studying tuna fisheries interactions and examination of their applicability; case-studies on tuna fisheries interactions; analyses of tuna fisheries involved in interactions and their management; and an overview of the FAO project that co-organized and co-sponsored the consultation. The consultation noted that the number of quantified interactions is still small, primarily because of difficulties associated with evaluating them. Interactions were found to vary in significance depending on the biological characteristics of the species involved, the sizes of fish caught, the local and stock-wide rates of exploitation and the distance among fisheries. In many of the studies presented, the inadequacy of fisheries data is stressed. In addition, the lack of understanding of the movements of the fish is noted in several papers. General qualitative guidelines presented in several discussion papers stress that specifically designed studies be undertaken to quantify interactions. Well-designed tagging experiments seem to provide the most reliable information about interactions. Guidelines for the collection of data, biological and ecosystem research, modelling and alternative methodologies for studying tuna fisheries interactions are also included. An indexed bibliography of papers on tuna and billfish tagging is appended.

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